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UNIVERSITY OF ILLINOIS BULLETIN

ISSUED WEEKLY

APRIL 1, 1913

No. 31

[Entered as second class matter Dec. 11, 1912, at the Post Office at Urbana, Ill., under the Act of Aug. 24, 1912]

FUEL ECONOMY IN THE OPERATION OF HAND FIRED POWER PLANTS



CIRCULAR No. 7

ENGINEERING EXPERIMENT STATION

PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

PRICE: TWENTY CENTS

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ENGINEERING EXPERIMENT STATION,
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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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APRIL, 1918

FUEL ECONOMY IN THE OPERATION
OF HAND FIRED POWER PLANTS

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ENGINEERING EXPERIMENT STATION

PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA



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FUEL ECONOMY IN THE OPERATION OF HAND FIRED POWER PLANTS

I. INTRODUCTION

1. *Purpose.*—The need for greater economy in the use of coal is too apparent, under present conditions, to need emphasis. The demand for coal is unprecedented, and production is proceeding at a rate which is barely, or perhaps not quite, keeping pace with the demand. The U. S. Geological Survey reports that, during 1917, approximately 545,000,000 tons of bituminous coal were produced and used in the United States. The demand, moreover, is increasing at the rate of about ten per cent per year, so that at present the rate of consumption is about 600,000,000 tons per year. Illinois produces about 12½ per cent of this amount, or 78,000,000 tons.*

Approximately 45,000,000 tons of bituminous coal are used within the state of Illinois, and of this amount about 6,000,000 tons are consumed in hand fired power plants. It is believed to be within the limits of practical attainment to effect a saving of from 12 to 15 per cent of this fuel. Expressed in tons and dollars, such a saving amounts to 750,000 tons, or \$3,500,000. The possible saving in the case of many individual plants is much greater than the percentage stated.

It is the purpose of this circular to present to owners, managers, superintendents, engineers, and firemen of hand fired power plants certain suggestions which, it is believed, will help them in effecting greater fuel economy in the operation of their plants, and in determining the properties and characteristics of the coal purchased. Features of installation essential to the proper combustion of fuel are discussed and their importance emphasized; the practice to be observed in the operation of the plant is outlined; and the employment of simple devices for indicating conditions of operation is prescribed.

Special attention is called to the fact that, to secure the greatest degree of success, coöperation between owners and managers, and the men who fire the coal is essential. Mechanical devices to increase

* It is estimated that Illinois will produce more than 85,000,000 tons of coal in 1918.

efficiency in the use of coal cannot produce satisfactory results unless the firemen who handle them are impressed with the importance of their duties. While the suggestions presented apply particularly to hand fired plants and no attempt is made to define practice for stoker fired plants, many of the factors affecting fuel economy are common to all power plants, and for this reason much of the information contained herein will, no doubt, be helpful to those interested in more economical operation of stoker fired power plants.

To the experienced engineer much that is presented here will seem elementary and inadequate. If, however, the plant owner who is not familiar with the extreme refinements of practice may obtain here the facts which will enable him to improve his results to the extent of the modest saving suggested, the purpose of the publication will have been fulfilled.

2. *Authorship.*—The information contained in this circular has been compiled under the direction of a committee consisting of A. C. WILLARD, Professor of Heating and Ventilation (Chairman), H. H. STOEK, Professor of Mining Engineering, O. A. LEUTWILER, Professor of Machine Design, C. S. SALE, Assistant Professor of Civil Engineering and Assistant to the Director of the Engineering Experiment Station, and A. P. KRATZ, Research Associate in Mechanical Engineering.

This committee has had the assistance of an advisory committee consisting of JOSEPH HARRINGTON, Advisory Engineer on Power Plant Design and Operation, Chicago, ARTHUR L. RICE, Editor, *Power Plant Engineering*, Chicago, JOHN C. WHITE, Chairman, Educational Committee, National Association of Stationary Engineers, Madison, Wis., O. P. HOOD, Chief Mechanical Engineer, Bureau of Mines, Washington, D. C., D. M. MYERS, Advisory Engineer on Fuel Conservation, United States Fuel Administration, Washington, D. C., and C. R. RICHARDS, Dean of the College of Engineering and Director of the Engineering Experiment Station of the University of Illinois. Each member of this Advisory Committee personally reviewed the original manuscript and a meeting was held at Urbana on March 21, 1918, at which the work was examined in detail. The authors gratefully acknowledge the valuable assistance and coöperation of the members of this committee and feel that the value of the publication has been greatly enhanced as a result of their efforts.

II. FUELS AVAILABLE FOR POWER PLANT USE IN THE MIDDLE WEST

3. *Kinds of Fuel.*—The varieties of fuel used by hand fired power plants in Illinois are:

Central bituminous coals as represented by those from the coal fields of Illinois, western Kentucky, and Indiana.

Eastern bituminous and semi-bituminous, or soft coals, from the Pennsylvania, West Virginia, and eastern Kentucky fields.

A classification of solid fuels available for this purpose will, of course, include anthracite and coke but none of these is used to any considerable extent for power purposes in Illinois. The liquid fuel, petroleum, is produced in large quantities in Illinois but is not used directly for fuel purposes to any great extent.

All these coals are composed of the following materials in varying proportions:

- (1) Solid or fixed carbon which burns with a glow and without flame.
- (2) Gases or volatile materials which escape from the coal when it is heated and which burn with a flame.
- (3) Gases or volatile matter and water which escape from the coal when it is heated and which do not burn.
- (4) Ash or mineral matter which does not burn and which remains as ashes after the coal is burned.

The relative proportions of these materials in different coals determine their value for particular purposes.* Fuels having a large amount of fixed carbon and a relatively small amount of volatile matter burn with a short flame and the whole process of combustion takes place at or near the surface of the fuel bed. Such fuels can be burned without developing visible smoke. On the other hand coals containing a relatively large amount of volatile matter and a lower proportion of fixed carbon burn with a longer flame and tend to produce more visible smoke than the high carbon coals because the volume of combustible gases distilled from them is greater.

The bituminous coals of the central field (Illinois type) contain

* The "fuel ratio," which is the quotient obtained by dividing the fixed carbon by the volatile matter, is often used as a means of classifying coals, and for bituminous coals it answers fairly well.

from 40 to 55 per cent of fixed carbon, 10 to 25 per cent of combustible gas, 5 to 15 per cent of non-combustible gas, 8 to 15 per cent of moisture, and 8 to 15 per cent of ash. When improperly fired or burned in furnaces not adapted to their use, central bituminous coals give off so large an amount of sooty material that flues are often quickly clogged. These unconsumed volatile products also represent a direct loss of heat value. Coals of the Illinois type ignite easily and burn freely.

Because the amount of solid carbon in most Illinois coal is lower and the percentage of ash and moisture higher its heating value is usually less than that of most eastern bituminous coals, but the cost is usually so much less that it is more economical to use local coals. At this time (March, 1918) the transportation of fuel over long distances is not only undesirable, but it is practically impossible, and bituminous coals of the central field constitute the only fuel available in quantities for use in Illinois.

The moisture and non-combustible gases present in all coals are detected only by chemical analysis. They not only do not produce heat, but represent a definite loss because they absorb and carry off heat which would otherwise be available for useful purposes. The term moisture in coal does not mean the water adhering to the surface of the lumps, but that contained within the pores of the coal. A coal containing a high percentage of moisture by analysis may appear perfectly dry.

The ash content of different coals varies greatly. Ash is non-combustible mineral matter which not only has no heating value and, therefore, represents a portion of the coal from which no return is received, but it may hinder the free burning of the combustible components of the coal. If the ash contains certain mineral substances, it may by clinkering greatly interfere with the process of firing and with the cleaning of grates. The ash normally is removed through the ashpit into which often passes also a certain amount of unburned coal. For this reason the amount of ashes removed from the pit usually represents a larger percentage of the fuel fired than the analysis of the ash content indicates. It should be clearly understood that ash will *not* burn and that no treatment with chemicals, or "secret processes," will cause it to burn. Likewise, it is not possible to increase the heat value of coal by treating it chemically or by adding a nostrum to it.

The ash in coal may be divided into two classes; first, that which is a definite part of the composition of the coal and which cannot be separated from the coal by hand or by mechanical process, and, secondly, that which is due to rock, slate, and shale which become mixed with the coal in mining and which can in a large measure be separated from the coal either in the mine or in the tipple.

Bituminous coal may be either of the coking or the non-coking variety. Coals vary widely with reference to their coking properties. A true coking coal when fired swells, becomes pasty and fuses into a mass of more or less porous coke. Such coke will burn without flame and will hold fire for a considerable period. This fusing or coking takes place without respect to the size of the piece of coal. A non-coking coal does not swell and become pasty but burns away gradually to ash, the pieces becoming gradually smaller and smaller. There is a gradual gradation from true coking to true non-coking coals and many coals cannot be distinctly placed in either class. Coal which will not coke on a furnace grate may, however, give good coke in by-product coke ovens, particularly when mixed with other more easily coking coals. This is the case with many Illinois coals.

The eastern bituminous coals contain from 5 to 10 per cent of ash, from 25 to 35 per cent of combustible gases, from 2 to 5 per cent of moisture and non-combustible gases, and from 55 to 65 per cent of solid carbon. They are more generally of the coking variety than are the Middle West coals. In general, they are higher in heating value and lower in ash. They are more friable and are not so well suited for transportation and repeated handling as are many of the central bituminous coals.

4. *Properties of the Central Bituminous Coals.*—Coals used in Illinois power plants come mainly from the Illinois, Indiana and western Kentucky fields. The properties of these coals as disclosed by analyses of samples from different localities are given in Table 1.

The average analyses of the important Illinois coals have been determined with great care. The averages for Kentucky were obtained by average analyses of composite samples from several mines. Average analyses are not available for Indiana coals and instead analyses are given of samples from three important Indiana coal counties, namely, Clay, Green and Sullivan counties.

TABLE 1

ANALYSES OF COALS OF ILLINOIS, INDIANA, AND WESTERN KENTUCKY
(Figures are for face samples and for coal "as received")¹

DISTRICT	Coal Bed	Moisture	Volatile Matter	Fixed Carbon	Ash	B. t. u. (Heating Value)
ILLINOIS (Average Analyses)						
La Salle.....	2	16.18	38.83	37.89	7.08	10,981
Murphysboro.....	2	9.28	33.98	51.02	5.72	12,488
Rock Island and Mercer Counties ..	1	13.46	38.16	39.75	8.63	11,036
Springfield-Peoria.....	5	15.10	36.79	37.59	10.53	10,514
Saline County.....	5	6.75	35.49	48.72	9.04	12,276
Franklin and Williamson Counties..	6	9.21	34.00	48.08	8.71	11,825
Southwestern Illinois.....	6	12.56	38.05	39.06	10.33	10,847
Danville: Grape Creek coal.....	6	14.45	35.88	40.33	9.34	10,919
Danville: Danville coal.....	7	12.99	38.29	38.75	9.98	11,143
INDIANA (Typical Analyses)						
Clay County.....	{ Brazil block }	15.38	32.66	46.08	5.88	11,680
Greene County.....	IV	13.53	33.54	45.38	7.55	11,738
Greene County.....	V	10.30	36.31	41.64	11.75	11,218
Sullivan County.....	IV	12.15	33.48	46.23	8.14	11,722
Sullivan County.....	V	12.14	35.17	43.73	8.96	11,516
Sullivan County.....	VI	14.86	31.65	46.14	7.35	11,324
KENTUCKY (Average of Composite Samples)						
	9	8.17	36.82	45.17	9.83	11,867
	11	7.33	38.28	45.28	9.11	12,056
	12	9.67	34.86	46.46	9.01	11,695

¹"As received" samples represent the coal as taken from the mine. It is probable that the values given are fairly representative of the coals as purchased from local dealers.

A study of the values presented in Table 1 reveals the following facts:

- (1) The amount of ash in the various coals as they exist in the mine varies within a range of about 6 per cent. With inadequate preparation of the coal for the market, however, the range of difference may be as much as 12 or 15 per cent.
- (2) There is a variation in the percentage values over a range of about 5 per cent in the volatile matter in the different coals, an amount which is negligible in view of the proportionately greater variations in heating value and in ash.

- (3) The variation in the amount of moisture present in the different coals is considerable, but this variation is reflected to some extent in the B. t. u.* values. If two coals have about the same amount of fixed carbon, volatile matter and ash, the coal having the higher moisture content has the lower B. t. u. value. Accordingly, if the B. t. u. value of a coal is known, the moisture content is not important. This statement is also true as regards ash, except that the ash represents a residue to be handled.

With regard to the B. t. u. values, the table shows that there are important and distinguishable differences in the heating quality of the different coals found in the three states, yet the extent of difference is not sufficient to justify extravagant statements in praise of certain coals or in disparagement of others. On the basis of heating value alone, the difference between the value of the poorest and that of the best coals, as they are found in the mine, amounts to about one-fifth of the value of the poorest coal.† As stated previously, however, the care with which coal is prepared affects its value as fuel (see section 5 "Preparation, a Factor Affecting the Value of Coal," p. 14).

The values given cover the most wide-spread and most important coal beds of Illinois, Indiana, and western Kentucky. It should be observed that the variations are as great between coals which come from the same bed in widely separated localities as between coals which come from different beds, for instance, the No. 6 coal of Franklin and Williamson counties differs nearly as much from the No. 6 coal of the Belleville region of southwestern Illinois as it does from the No. 5 coal of Saline County. For large areas, however, the characteristics of each bed are remarkably constant and variations in the character of the coal are regional rather than local. It is possible therefore, to subdivide the large coal fields of the three States into districts as shown on the accompanying map (Fig. 1).

The subdivisions of the Illinois field as shown on this map were based mainly upon geological conditions and upon the general sim-

* For a definition of B. t. u. see foot-note on page 17.

† Comprehensive tables giving analytical values for Illinois coals are contained in Bul. 29 of the State Geological Survey, Urbana, Ill., entitled "Purchase and Sale of Illinois Coal under Specifications," by S. W. Parr, and in Bul. 3 of the Illinois Coal Mining Investigations, Urbana, Ill., entitled "Chemical Study of Illinois Coals," by S. W. Parr. Professional Paper 100A, U. S. Geological Survey, Washington, D. C., contains analyses of coals from all parts of the United States.

ilarity in the methods of mining in each district rather than upon a difference in the quality of the coal. This fact should be understood in considering the analyses of coals from the different districts. For instance, the coals from the eastern part of Perry County are very similar to those from Franklin and Williamson counties, although classed by the map as being in a different district. The dividing line accepted by the Illinois Coal Mining Investigations between District 6 and the southern part of District 7 is the Duquoin anticline, a distinct geologic structural feature which has, however, not effected any distinct change in the character of the coal, that just west of and near the anticline being practically of the same quality as that east of the anticline in the same locality.

The several Illinois coals do not differ materially in appearance and it is often difficult to distinguish one from another without more careful tests than the ordinary purchaser can make. The apparent difference is frequently due to preparation rather than to actual differences in chemical composition and in heating quality.

5. *Preparation, a Factor Affecting the Value of Coal.*—Coal occurs in the earth in beds or seams, and usually in a solid mass as a rock. In mining it is blasted with powder, shoveled into cars, and conveyed to the surface. In the process of mining and handling it becomes broken up into pieces of all sizes. It may have some rock or dirt from the floor and roof of the mine mixed with it or there may be bands or layers of earthy matter in the coal seam itself. Coal as it comes from the mine is therefore not usually in condition for immediate delivery to the consumer, but ordinarily must first be “prepared” in order to remove these impurities and to separate it into the proper sizes for various purposes or markets. The impurities in the large sizes of coal are removed by picking them out by hand, and in the smaller sizes by treating the coal in cleaning machinery. Separation into different sizes is accomplished by sending the coal over screens having holes of the proper size.

Table 2 gives the customary sizes and the corresponding names of central bituminous coals as they are available in the market.

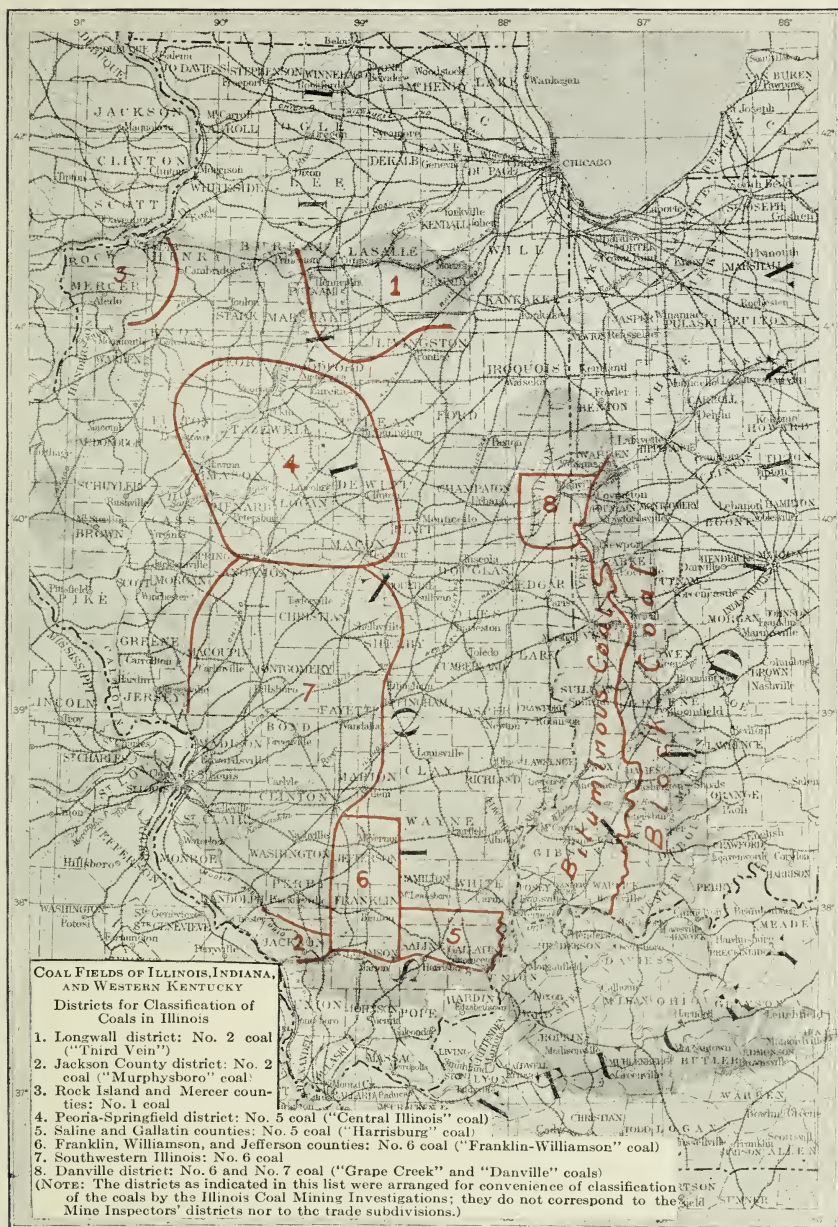


FIG. 1. MAP SHOWING THE LOCATIONS OF THE COAL FIELDS OF ILLINOIS, INDIANA, AND WESTERN KENTUCKY

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TABLE 2
SIZES OF CENTRAL BITUMINOUS COALS

NAME	SIZE OF PIECES
Run of Mine	Mixture of all sizes
Lump	Large lumps separated from the finer sizes
Egg or Furnace	Lumps 3-6 inches
No. 1 Nut or Small Egg	2-3 inches
No. 2 Nut or Stove	1¼-2 inches
No. 3 Nut or Chestnut	¾-1¼ inches
No. 4 Nut or Pea or Buckwheat	¼-¾ inch
No. 5 Nut	Under ¼ inch
Screenings	A mixture of all sizes under 2 inches

For large power plants the custom of purchasing coal on the B. t. u.* basis is increasing and if the specifications for such purchase are properly drawn and understood it is the logical way to buy coal, because it is equivalent to buying so many heat units instead of so many tons of coal. Upon this basis a purchaser should be able to determine whether a low priced coal which gives less efficient boiler service and involves greater expense for handling ashes is really cheaper than a higher priced coal.

With reference to the selection of different Illinois coals, the B. t. u. value and the percentage of ash furnish a general guide to their relative values. If two coals are otherwise alike in composition, the ash content increases as the B. t. u. value decreases; hence their relative values may be expressed with fair accuracy by either the B. t. u. or the ash value alone, although the evaporative value of any coal drops off more rapidly than its B. t. u. value when the ash content exceeds 10 or 15 per cent. A close approximation of the percentage of actual heat producing material in Illinois coal may be obtained by dividing the B. t. u. value of the coal by 155. Thus, a 12,000 B. t. u. coal contains $12,000 \div 155$, or 77 per cent of heat-producing material. In order to enable the small consumer to judge the relative values of coals offered at different prices, the chart, Fig. 2, has been prepared

* B. t. u. is a term made use of by engineers to express a certain amount of heat. It is an abbreviation of "British thermal unit." One B. t. u. is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. If a coal has a heating value of 14,000 B. t. u., there is sufficient heat in one pound of it to raise 14,000 pounds of water one degree Fahrenheit.

to show the theoretical value of coals of different heating or B. t. u. values at various prices per ton.

It should be understood that the purchase of coal on the B. t. u. basis does not insure a maximum evaporative value from the fuel, because a high-grade coal carelessly fired may give poorer results than a low-grade coal carefully fired. In other words, the B. t. u. value of a coal is simply an indication of what should be obtained with careful firing and the person who furnishes coal of a high B. t. u. value cannot be held responsible for poor results obtained from that coal through improper use. It should also be remembered that while the B. t. u. value shows the chemical composition, it indicates nothing with regard to the physical properties of the coal, and these properties may be equally as important as the chemical properties in their effects upon firing, storing, and transportation.

6. *Storage of Coal.*—The storage of a certain amount of coal by every power plant is both desirable and essential in order to insure continuous operation. Although there is some misapprehension with regard to the practicability of storing bituminous coal, a study of the subject based upon the reported experience of more than a hundred firms and individuals indicates that the difficulties attending storage are not serious.* These investigations have shown that:

- (1) It is practicable and advantageous to store coal, not only during war times, but also under normal conditions, near the point of consumption. The practice of storing coal has the advantage of (a) insuring the consumer a supply of coal at all times, (b) permitting the railroads to utilize their cars and equipment to the best advantage, and (c) permitting the mines to operate at a more nearly uniform rate of production throughout the year. The expense of storage may be regarded as the expense of insurance against shut-downs.
- (2) Certain requirements affecting the kinds and sizes of coal must be observed as follows:
 - (a) Most varieties of bituminous coal can be stored successfully if of proper size and if free of fine coal and dust. The coal must be so handled that dust and fine coal are not produced

* For a more nearly complete discussion of the problem of coal storage, see Bulletin 97 of the Engineering Experiment Station, University of Illinois, entitled "Effects of Storage Upon the Properties of Coal," by S. W. Parr, and Circular 6 of the Engineering Experiment Station, University of Illinois, entitled "The Storage of Bituminous Coal," by H. H. Stock.

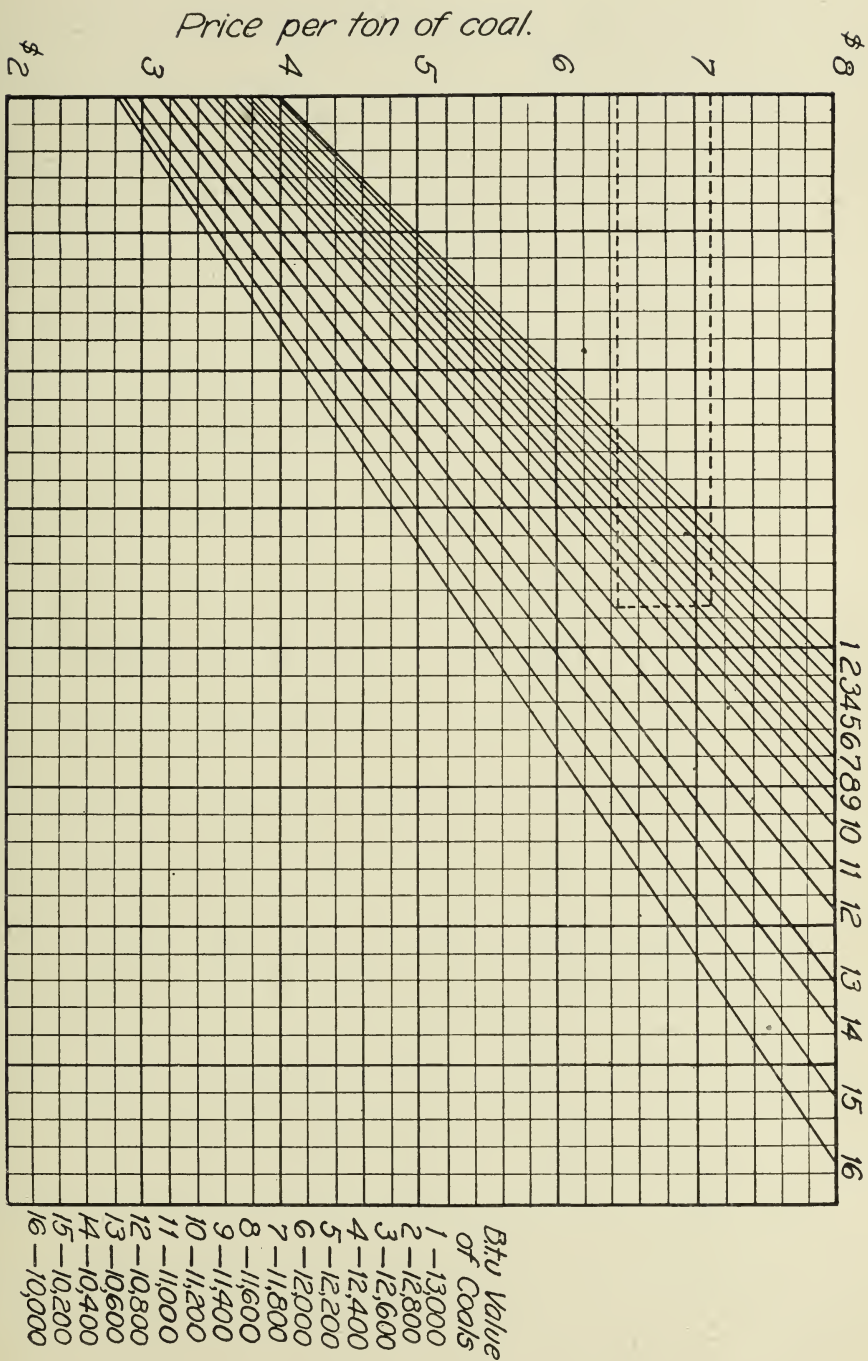


FIG. 2. CHART SHOWING THE THEORETICAL VALUE OF COALS OF DIFFERENT HEATING VALUES AT VARIOUS PRICES PER TON

To make a comparison between coals of different B. t. u. values, locate the point on the line representing the B. t. u. value of the coal in question directly opposite the price involved. Through this point draw a vertical line, and from the intersection of this with the diagonal lines representing any other B. t. u. value read the comparable price from the price scale at the left. For Example: If a 12,000 B. t. u. coal is offered at \$7.10 per ton, a coal having a heating value of 11,000 B. t. u. will be worth \$6.45.

in excessive amounts, and allowed to remain during storage. Although some coals can be stored with greater safety than others, the danger from spontaneous combustion is due more to improper piling of the coal than to the kind of coal stored. The danger of spontaneous combustion can be very greatly reduced if not entirely eliminated by storing only lump coal from which the dust and fine coal have been removed.

- (b) Fine coal or slack has sometimes been stored successfully in cases in which air has been excluded from the interior of the pile. Exclusion of air from the interior of a pile may be accomplished (a) by a closely sealed wall built around the pile, or (b) by very close packing of the fine coal. A pile of slack must be carefully watched to detect evidences of heating and means should be provided for moving the coal promptly if heat develops. The only absolutely safe way to store slack or fine coal is under water.
 - (c) Many varieties of mine run bituminous coal cannot be stored safely because of the presence of fine coal and dust.
 - (d) Coal exposed to the air for some time may become "seasoned" and thus may be less liable to spontaneous combustion because of the oxidation of the surfaces of the lumps. Experience covering this point, however, is by no means conclusive.
 - (e) It is believed by many that damp coal or coal stored on a damp base is peculiarly liable to spontaneous combustion, but the evidence on this point also is not conclusive. It is safest not to dampen coal when or after it is placed in storage.
- (3) The sulphur contained in coal in the form of pyrites is not the chief source of spontaneous combustion, as was formerly supposed, but the oxidation of the sulphur in the coal may assist in breaking up the lumps and thus may increase the amount of fine coal, which is particularly liable to rapid oxidation. The opinion is wide-spread that, if possible, it is well for storage purposes to choose a coal with a low sulphur content.
- (4) In piling coal for storage the following conditions should be observed:
- (a) To prevent spontaneous combustion, coal should be so piled

that air may circulate through it freely and thus may carry off the heat due to oxidation of the carbon, or it should be so closely packed that air cannot enter the pile and stimulate the oxidation of the fine coal.

- (b) Stratification, or segregation of fine and lump coal, should be avoided, since an open stratum of coarse lumps of coal may provide a passage or flue for air to enter and come in contact with the fine coal, and thus to oxidize it and start combustion.
- (c) Coal can be stored with greater safety in piles not more than six feet high than in piles of greater height since the coal is more fully exposed to the air in low piles, the superficial area of the pile in relation to its volume being greater. The coal pile should preferably be divided by alleyways so as to facilitate the rapid removal of the coal in case of necessity and so that an entire pile may not be endangered by a local fire.
- (d) The practice of ventilating coal piles by means of pipes inserted at intervals has not proved generally effective as a means of preventing spontaneous combustion in storage piles in the United States and it is not advised. Such practice is, however, reported to have been successful in certain parts of Canada.
- (e) Coals of different varieties should not be mixed in storage, because a single variety of coal which has a tendency toward spontaneous combustion may jeopardize the safety of the entire pile.
- (f) Storage appliances and arrangements should be designed so as to make it possible to load out the coal quickly if necessary. *Coal should positively not be stored in large piles unless provision is made for loading it out quickly.*
- (g) Pieces of wood, greasy waste, or other easily combustible material mixed in a coal pile may form the starting point of a fire, and every precaution should be taken to keep such material from the coal as it is being placed in storage.
- (h) It is very important that coal in storage should not be affected by external sources of heat such as steam pipes. The susceptibility of coal to spontaneous combustion increases rapidly as the temperature rises.

- (5) The effects of storage on the value and properties of coal may be summarized as follows:
- (a) The heating value of coal as expressed in B. t. u. is decreased very little by storage, but the opinion prevails that storage coal burns less freely than fresh coal. Experiments indicate that much of this apparent deficiency may be overcome by keeping a thin bed on the grate and by carefully regulating the draft to suit the fuel.
 - (b) The deterioration of coal when stored under water is negligible, and such coal absorbs very little extra moisture. If only part of a coal pile is submerged, the part exposed to the air is still liable to spontaneous combustion.
- (6) In order to guard against loss in the event of fire in a pile of stored coal the following facts should be understood:
- (a) The best means of preventing loss in stored coal is to inspect the pile regularly and if the temperature in any part of the pile rises to 150 degrees F. to prepare to remove the coal from the spot affected. If the temperature continues to rise and reaches 175 degrees F., the coal should be removed as promptly as possible. Temperature readings may be taken by lowering a thermometer into the interior of a pile through a pipe driven into it. The common methods of testing for fires in coal piles are:
 - (1) By watching for evidences of steaming.
 - (2) By noting the odor given off.
 - (3) By inserting an iron rod into the pile and when drawn out noting the temperature by applying the hand.
 - (4) By inserting maximum temperature thermometers into pipes driven into the pile.
 - (5) By noting spots of melted snow on the pile.
 - (b) Water is an effective agent in quenching fires in a coal pile only if it can be applied in sufficient quantities to extinguish the fire and to cool the mass, but unless there is an ample supply for this purpose it is dangerous to add any water to a coal pile.

7. *Storage Systems.*—Since coal is a comparatively cheap and bulky product, it must be handled as economically as possible, and also,

unless it is to be used in the form of screenings, in a way to produce a minimum of breakage.

The ordinary power plant is frequently limited in the choice of a storage system by a lack of available space and by the fact that expense must be kept at a minimum, but it should be recognized that provision for storage may be counted as an insurance against interrupted operation. The storage may be temporary or permanent, that is, the coal may be stored for use within a comparatively short time or it may be stored with the expectation that it will remain in storage for a considerable period to serve as a reserve in case of an emergency, the current daily supply being used as received.

At hand fired power plants coal is usually stored by dumping or shoveling from a car or cart upon a pile or into a bin or bunker, or merely by dumping upon the ground. From such storage piles coal is shoveled directly into the furnace or, if the pile is at some distance from the furnace, carried by wheelbarrow or conveyor to the furnace.

Trestle storage involves the dumping of the coal directly upon the ground or into a bin from cars on an elevated trestle. Although simple in construction and low in first cost, trestle storage produces excessive breakage and unless drop-bottom or dump cars are available the cost of unloading is high.

The cost of storing and reclaiming coal from storage by manual labor varies from 15 to 64 cents.*

WARNING:—Special emphasis is laid upon the fact that safety in the storage of coal depends upon a very careful and thorough consideration of and attention to the details referred to in the foregoing. Lack of attention to these details and lack of care in handling will in many cases result in losses due to dangerous fires. Do not undertake to store coal until you are sure you know how to do it properly and safely.

* Stoeck, H. H., "The Storage of Bituminous Coal," Univ of Ill Eng. Exp. Sta., Circ 6, 1918.

III. THE COMBUSTION OF FUEL AND THE LOSSES ATTENDING IMPROPER FIRING

8. *Principles of Combustion.*—The combustion of coal in a furnace is essentially a chemical process. The combustible in coal consists of carbon,* hydrogen and sulphur. During the progress of combustion these elements unite with oxygen to form carbon dioxide, steam, and sulphur dioxide respectively. The air, which furnishes the oxygen for this process, consists of a mixture of 21 per cent by volume of oxygen and 79 per cent of nitrogen. Oxygen is the active element as affecting combustion, the nitrogen being inert and taking no part in the process.

When combustion takes place, heat is given off. For every pound of carbon burned to carbon dioxide, 14,600 B. t. u.† are released. In the same way, for every pound of hydrogen burned to water vapor 62,100 B. t. u. are liberated. One pound of sulphur in burning to sulphur dioxide gives up 4,000 B. t. u. The heat liberated serves to raise the temperature of the fuel bed, of the surrounding surfaces, and of the products of combustion. Part of the heat delivered to the water in the boiler is transmitted by direct radiation from the hot surfaces, and the rest is absorbed by conduction from the gases, thus lowering their temperature. The heat carried away by the gases after they have left the heating surfaces of the boiler represents the loss entailed in the process. The extent of this loss is, of course, indicated by the temperature of the gases leaving the heating surfaces. The nitrogen, as stated, takes no part in combustion, but on the contrary it absorbs a certain amount of heat in having its temperature raised from that of the air to that of the gases leaving the fire. Consequently, the temperature of the other gases does not reach so high a point as would be possible if oxygen alone could be introduced into the fuel bed. When the nitrogen leaves the heating surfaces with the rest of the gases, it carries away part of the heat released by the fuel, and,

* The chemical symbols used for these elements and compounds are as follows: Carbon (C), hydrogen (H), sulphur (S), oxygen (O), carbon dioxide (CO_2), steam (H_2O), sulphur dioxide (SO_2), nitrogen (N), and carbon monoxide (CO). Carbon dioxide is variously known as carbonic acid gas and as black damp, while carbon monoxide is known as carbonic oxide and as white damp.

† For definition of B. t. u. see foot-note on page 17.

therefore, represents loss. This loss amounts to about 0.24 B. t. u. per pound of nitrogen per degree F.

In the process of combustion, one pound of carbon unites with 2.67 pounds of oxygen to form 3.67 pounds of carbon dioxide. Since the composition of the air is 77 per cent nitrogen and 23 per cent oxygen by weight, 2.67 pounds of oxygen requires 11.6 pounds of air.

One pound of hydrogen in burning unites with eight pounds of oxygen to form nine pounds of water vapor. In this case the amount of air required is 34.8 pounds.

One pound of sulphur in burning unites with one pound of oxygen to form two pounds of sulphur dioxide. The air required is 4.35 pounds.

It is evident that if the weights of carbon, hydrogen, and sulphur in one pound of coal are known, the air necessary to burn completely one pound of coal amounts to 11.60 times the weight of carbon, plus 34.80 times the weight of hydrogen, plus 4.35 times the weight of sulphur. This is about 12 pounds of air per pound of coal.*

Every cubic foot of oxygen used in the combustion of carbon is replaced by one cubic foot of carbon dioxide. For this reason, the percentage by volume of CO_2 in the flue gas is an indication of the amount of excess air present in the furnace. A given amount of CO_2 will be formed for every pound of carbon burned. If just enough air is used for the complete combustion of the carbon, the oxygen will be replaced by the CO_2 formed and the latter will be the same percentage, by volume, of the mixture as the original oxygen. If twice as much air as necessary is used, the same volume of CO_2 will be formed as before, but this will replace only one half of the oxygen used, and hence its percentage of the mixture will be only one half as great as in the former case. These relations are somewhat affected by the fact that hydrogen and sulphur are present, but their amounts are too small to have an important bearing on the result.

If less than enough air is furnished for complete combustion, part of the carbon in the coal, instead of being burned to carbon dioxide, will form carbon monoxide. Under these circumstances the amount of heat liberated per pound of carbon, instead of being 14,600 B. t. u. will be only 4,500 B. t. u. The difference, 10,100 B. t. u., will represent the heat lost for every pound of carbon burned to carbon monoxide.

* Any air above the chemical requirement for complete combustion is known as excess air.

Since combustion is the result of the union of oxygen with the various elements in the coal, and with the combustible products formed in the fuel bed, it necessarily follows that in order to have complete combustion, each particle of these elements must come into contact with a sufficient amount of oxygen. To insure this contact between the particles of the combustible and oxygen, it is necessary to supply an amount of oxygen, and hence of air, somewhat in excess of the amount theoretically required; otherwise carbon monoxide will be found in the escaping gases. This excess acts as a further diluent, and represents loss, just as the nitrogen in the air represents loss. A compromise must, therefore, be made. The correct amount of air to be used is obtained when the loss due to heating the excess just balances the loss due to the carbon monoxide appearing if the excess is reduced. For best operating conditions it is found necessary to use between 30 and 40 per cent of excess air.

Before the union of oxygen and the elements in the coal can take place with sufficient rapidity to be of any practical use, it is necessary that the whole mass be brought to a temperature known as the ignition temperature. If, because of any condition, such as contact with the cold surfaces of the tubes or the inrush of an excessive amount of cold air, the temperature of the gases is lowered below the ignition point before combustion is complete, combustion will cease and part of the fuel will escape from the furnace unburned. This, of course, represents a loss.

The three fundamental conditions necessary for complete and smokeless combustion may now be stated as follows:

- (1) A sufficient amount of air must be supplied.
- (2) The air and fuel must be intimately mixed.
- (3) The mixture must be brought to the ignition temperature and maintained at this temperature until combustion is complete.

9. *Significance of Draft.*—The technical meaning of the term “draft” does not refer to the motion of the air or gases, but merely defines the difference in pressure existing between the air outside and the gases inside the furnace (See Figs. 3 and 13). If there is an opening into the furnace and the draft is maintained, air will be forced in from the outside. The amount of air which passes will depend upon the size of the opening and the resistance offered to the flow;

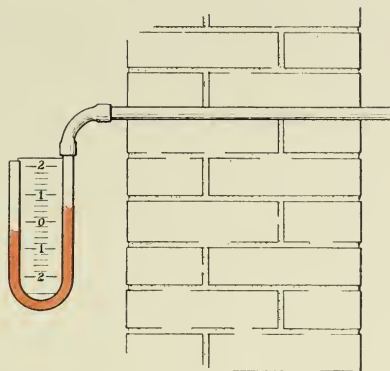


FIG. 3. MANOMETER TUBE FOR SHOWING THE DIFFERENCE IN PRESSURE BETWEEN THE OUTSIDE AND THE INSIDE OF A BOILER WALL

hence the weight of air passing through the fuel bed from the ash-pit for any given draft over the fire will depend upon the thickness of the bed, the size of the pieces of coal, and the condition of the bed. In any case, the combustion of a given amount of coal always requires a definite amount of air. Since for large pieces of coal the voids in the fuel bed are correspondingly large, a fuel bed of given thickness will present less resistance to the passage of air than a bed of finer coal of the same thickness. Hence it requires less draft with large coal than with fine coal to pass a given amount of air through the fuel bed. It is, however, advisable to use a thicker bed with large coal in order to close up the holes. This in turn will make it necessary to increase the draft to a point about equal to that used for fine coal, although the exact relation existing between thickness of bed, draft, and load on boilers must be determined by experiment in each case.

In view of facts developed in a recent investigation,* special attention should be given to the regulation of the overdraft in hand fired furnaces, since, contrary to the generally accepted belief, it is shown

* "Combustion in the Fuel Bed of Hand Fired Furnaces," by Henry Kreisinger, F. K. Ovitz, and C. E. Augustine, Tech. Paper No. 137 U. S. Bur. of Mines, Washington, D. C. The investigation reported in this publication discloses the following facts: "The current of air in passing through a uniform fuel bed without holes will have all its oxygen used within the first four inches from the grate. The rate of combustion therefore varies directly with the rate at which air is forced through a uniform fuel bed. The completeness of combustion is determined by mixing volatile gases with air in the space above the fuel bed. The reactions here are between two gases rather than between a solid and a gas, and the space required for this process is much greater. If only the theoretical amount of air is here available, the mixing may not be sufficiently perfected before the gases have passed out of the combustion space. Hence it is necessary to supply an excess amount of air over the fuel bed. This air must be introduced through openings above the fuel bed or come in through holes in the fire."

that most of the excess air is admitted into the combustion chamber above the fuel bed instead of through the fuel bed.

Every boiler should be equipped with two draft gages, one connected directly into the space over the fire (Fig. 4), and one connected

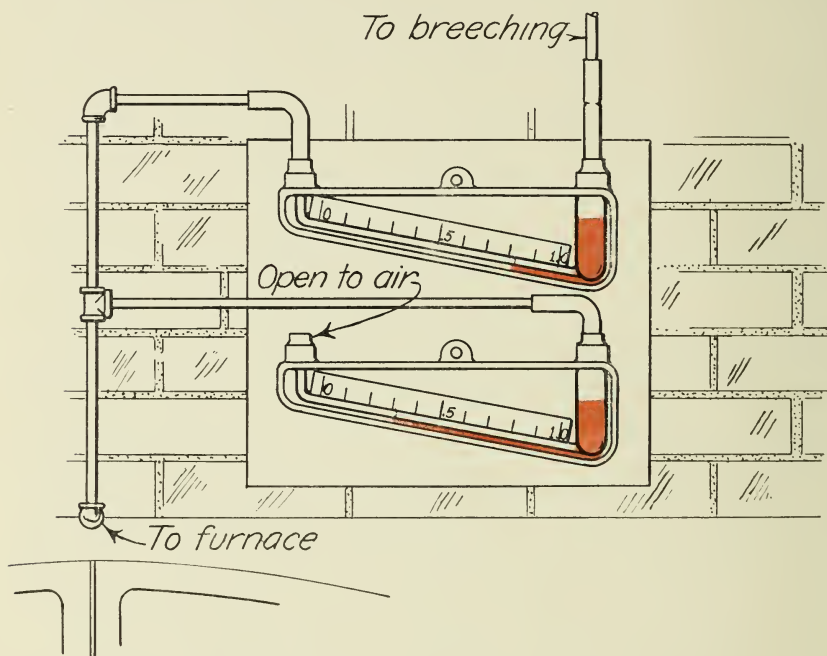


FIG. 4. SKETCH SHOWING THE CORRECT METHOD OF CONNECTING DRAFT GAGES

both into the space over the fire and into the gas passage below the damper, giving the drop in pressure through the tubes and baffling. The operation of the boilers should be controlled by means of the draft over the fire. The draft necessary to carry any given load and the corresponding proper thickness of fuel bed with the grade of coal used should be determined. With everything in good shape and no leaks in the setting and a given draft over the fire, there should be a definite loss of draft through the setting, or differential draft as it will hereinafter be called. When the damper is opened to increase capacity, both the furnace draft and the differential draft will increase. Assuming that the correct thickness of fuel bed is being used, an increase in the differential draft reading over the normal reading with the given

furnace draft indicates that there are holes in the fuel bed or that the tubes have become clogged with soot and ash. A decrease in the differential draft indicates that the fuel bed is dirty and that the resistance is greatly increased by ash or clinker, or that some of the baffling is down, causing a short circuit of the gases.

10. *Significance of CO_2 in the Flue Gases.*—A study of the amount of carbon dioxide (CO_2) in the flue gases affords the only practical means of obtaining a knowledge of conditions existing within the furnace on the basis of which correction or regulation to obtain the best results may be made. The importance of making CO_2 determinations, therefore, warrants a discussion of the methods by which these determinations may be made. Every plant should be equipped with some form of CO_2 analyzing apparatus and the fireman or other employe taught to use it. Since it is comparatively inexpensive, the outlay will be returned many times by the gain in efficiency and the consequent saving of fuel. For this purpose an Orsat apparatus or some of its modified forms should be used. The complete Orsat apparatus provides a means of analyzing for carbon dioxide, oxygen, and carbon monoxide, but since the CO_2 values give a sufficiently accurate indication of the amount of excess air passing through the fire, the analysis for the other two gases may be omitted and the apparatus used in its simplest form, as shown in Fig. 5. This consists merely of of a pipette, *h*, to hold the solution (potassium hydroxide), a measuring burette, *e*, of 100 cubic centimeters capacity, a leveling bottle, *f*, containing water, and an aspirating bulb, *m*. The solution may be made by mixing equal weights of potassium hydroxide (KOH) and water. In the absence of this chemical, concentrated lye may be used.

In using the CO_2 apparatus, the liquid in the pipette, *h*, is first brought to the mark, *o*, just below the cock, *d*. This can be done by lowering the leveling bottle, *f*, after which the cock, *d*, should be closed. The 3-way cock, *c*, is then opened to the burette, *e*, and to *b*, and by raising the leveling bottle, *f*, the water in the burette is brought to the mark, *g*, and the cock, *c*, closed to the burette, and opened through *a* and *b*. The aspirating bulb, *m*, is now worked, drawing gas from the sample tube, *n*, in the setting and forcing it out through *b*. When sufficient gas has been forced through to clean out the air and dead gas from the sample tube, the cock, *c*, is

turned so that *b* is closed, and *a* is in communication with the burette, *e*. The sample is then pumped into the burette, thus driving the water into the leveling bottle and more than filling the burette. The leveling bottle is then raised until the water in the

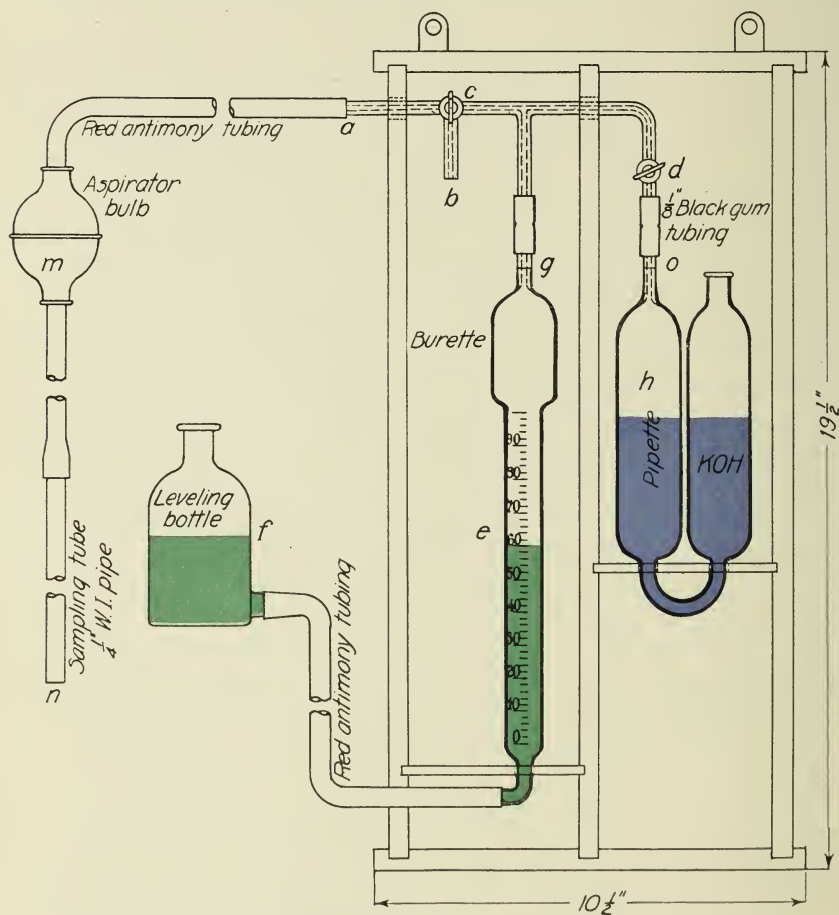


FIG. 5. APPARATUS FOR THE DETERMINATION OF CO₂ IN FLUE GAS

burette stands exactly at 100 cc., the rubber tubing between the leveling bottle and the burette is clamped between the thumb and finger so that no change in the level at 100 cc. can take place and the cock, *c*, momentarily opened to the atmosphere through *b* and then closed to the burette. If this has been done correctly, when the two

surfaces, *e* and *f*, are brought to the same level, *e* should stand at 100 cc. An alternate method of obtaining 100 cc. at atmospheric pressure is to have the 3-way cock open through *a* to *c* and closed to *b*. The gas may now be forced out through the liquid in the leveling bottle, *f*. The water at *f* and *e* may now be brought to the same level and the cock closed to the burette, *e*. The cock, *d*, is now opened and the gas driven into the pipette, *h*, by raising the leveling bottle. It should be driven back and forth between the burette and pipette several times, and then the liquid in the pipette brought back to the mark, *o*, and the cock, *d*, is closed. The surfaces, *f* and *e*, are again brought to the same level, and the amount of CO_2 in the gas sample is read from the burette at *e*. This operation is easily performed and a fireman of ordinary intelligence can analyze a sample in about two minutes.

There are several precautions which should be observed in taking samples. There must be no leaks in the rubber tubing or connections. If air leaks in during the analysis, it invalidates the result. The sole object in making an analysis is to determine what the fire is doing at the time the sample is taken; hence the apparatus should be hung on the setting at a point as near as possible to the point where the sample is taken in order to reduce the amount of piping and rubber tubing between the sampling tube and the analyzer, and to insure a sample representative of conditions at the time. If the sample is conveyed through tubes of considerable size and length, as is usually the case with a CO_2 recorder or even with a CO_2 indicator, the analysis is made from 5 to 15 minutes after the sample is taken. Thus a hole in the fire may be disclosed by the analyzer 5 or 10 minutes after its initial occurrence and even after its disappearance by filling up. The CO_2 recorder, therefore, is useful for giving an idea of the average operation over a long period, but is not satisfactory as a means of determining the proper relation between load, draft, fuel bed thickness, and other conditions. The determination of such relations involves simultaneous readings.

Precautions must be observed in inserting the sampling tube. An elaborate sampling apparatus used in the hope of obtaining an average sample is not to be recommended. Such apparatus consists mainly of a double tube arrangement having a series of small holes drilled into the tubes, the tubes extending across the gas passage. These do not accomplish the desired result, however, be-

cause the holes become clogged with soot and ash making it impossible to know the point in the flue from which the sample is drawn. Another reason why these tubes are not reliable for procuring an average sample lies in the fact that the gas stream varies across the flue in all directions, while the sampling tubes can at best give an average in only one direction. In order to obtain an exact average

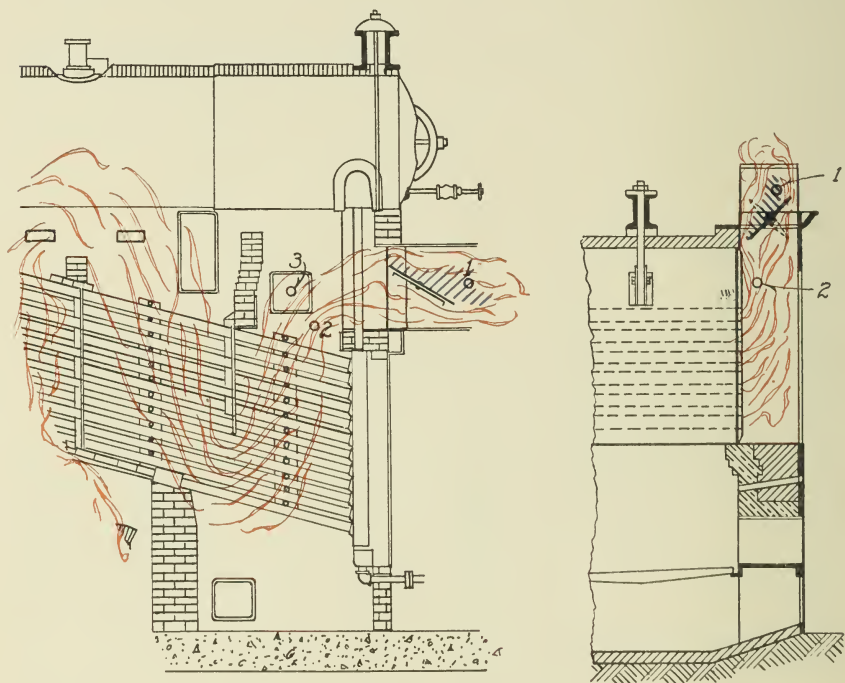


FIG. 6. SKETCH SHOWING THE PROPER LOCATION FOR GAS SAMPLING TUBES TO AVOID DAMPER POCKETS FOR BOTH FRONT AND REAR TAKE-OFF

Point 2 is in the center of the main gas stream and indicates correct position of the sampling tube. Points 1 and 3 show locations of pockets in which representative samples cannot be secured.

it would be necessary to fill the flue with a network of sampling tubes so arranged that each might take a quantity of gas proportional to the velocity of the stream at its point of sampling. For all practical purposes, therefore, it is best to take a sample through the end of a straight tube consisting of a piece of $\frac{1}{4}$ -inch pipe so that the point of sampling may be known with accuracy. A sample taken from the center of the main gas stream where the gas has

the greatest velocity has been found to yield an accurate indication of the condition of the fuel bed at the time of sampling, slight variations in the condition of the fire being reflected immediately in the sample. In placing the tube, care should be taken to have the end in the center of the main gas stream at point No. 2, Fig. 6, and not in any of the dead gas pockets as indicated by points 1 and 3. Otherwise low CO_2 values not representative of the actual conditions will be obtained. The tube should be inserted at the point where the gases leave the heating surfaces of the boiler for the last time as indicated by point 2 in Fig. 6, and not further out in the flue. An iron tube should not be used if the temperature at the point of sampling is sufficient to raise it to a red heat, because the character of the sample may be affected by part of the oxygen in the sample uniting with the red hot iron. A small cotton filter, contained in a glass tube, should be inserted between the sampling tube and the aspirator bulb. In using the apparatus shown on page 30, care should be taken to prevent a draft of cold air striking the burette during a reading. A material change in temperature during a reading will invalidate the result.

11. *Losses of Heat Value.*—The losses in the boiler plant may be divided into two classes:

- (1) Those due to the loss of green coal in handling.
- (2) Those resulting in the process of combustion. Losses of the first class are usually small and easily detected; hence they will not be discussed further.

The principal losses are those entailed in the process of combustion. These may be divided into the following classes:

- (1) Loss due to excess air and air leakage through the setting.
- (2) Loss due to combustible in ash.
- (3) Loss due to CO_2 formed.
- (4) Loss due to soot on the tubes.
- (5) Loss due to moisture carried in with the coal and air.
- (6) Loss due to heat carried out by the escaping gases.
- (7) Loss due to radiation.

Losses included under classes 1 to 4, inclusive, are largely preventable, while those under classes 5, 6 and 7 are more or less inevitable, although they may be reduced to a minimum with proper care.

Excess Air and Air Leaks

Losses due to excess air and to air leaks are discussed together because they may both be detected by the same means, *i. e.*, by analysis of the flue gas. Under the head of excess air may be included all air which goes through the combustion zone in excess of the amount required for perfect combustion. Air leakage includes all air going through holes in the setting and other places besides the fuel bed.

The space inside the average boiler setting is at less than atmospheric pressure; hence if there are any openings in the setting, air will leak through from the outside. This cold air not only takes no part in the combustion, but its temperature must be raised to that of the rest of the gas, a process which requires heat and lowers the temperature of the other gases. Some of this heat is given back to the water in the boiler, but all that indicated by the difference between the temperature of the flue gas and that of the air in the boiler room represents a dead loss. This is also true of the excess air carried through the fuel bed. While these losses cannot be detected with the naked eye, like that due to green coal in the ash, they are by far the most serious of all losses occurring in the average plant.

Leaks in the setting may occur in the metal work around doors and joints as well as in the brickwork. When leaks are found they should not only be stopped with asbestos or stove putty, but should be calked with waste or asbestos fiber soaked with fireclay in such manner as to prevent cracking off or falling out as soon as dry. The last of the leaks may best be found by building a smoky fire and shutting the damper. Smoke may then be seen to issue wherever there is a leak. When the setting has been made as tight as possible, air will still seep in because the bricks and the mortar are porous. This leakage may be reduced to a minimum by tacking metal lath to the setting and applying a coat of plaster one inch or so in thickness made of a mixture of about 80 per cent magnesia and 20 per cent old magnesia pipe covering. In order to secure a satisfactory surface 85 per cent magnesia should be mixed with cement to form a thin grout, spread on the surface, troweled to a smooth finish, and painted. This makes a good lagging not affected by temperature changes and also serves to reduce the radiation loss listed under class (7). If the setting is too hot to permit touching it with the hand without discomfort, the radiation loss is excessive.

After the setting has been made absolutely tight it will pay to

give attention to the excess air loss, but it is well to emphasize that the former should be done first. There exists a very definite relation between capacity, draft, fuel bed thickness, and air passing through the fuel bed with a given grade of coal. For Illinois coal a draft of approximately .01 inch of water is required to burn one pound of coal per square foot of grate surface per hour. This ratio is slightly increased for rates of combustion above twenty-five pounds of coal per square foot per hour.

In order to determine these relations in any given plant, a time should be chosen when the load on the boilers will remain constant for several hours. The fire should be clean, of uniform thickness, and free of holes, and the surfaces of the tubes should be free of soot. A draft and fuel bed thickness sufficient to maintain the load without loss of pressure should then be chosen. Simultaneous readings of the draft and analyses of the flue gas should now be made as rapidly as possible and repeated at brief intervals to insure permanence of conditions, and a watch should be kept on the fire to see that holes do not develop. Care must be taken not to open the furnace doors during a reading. Records should be kept of the drafts, CO_2 , and fuel bed thickness. Thickness of fuel bed should then be varied and the draft adjusted to carry the load without pressure drop, or without blowing the safety valves. When sufficient time has elapsed to allow conditions to become constant, another set of readings should be taken. If too thin a fuel bed were used at the start, it will be found on comparing the readings that as the thickness of the fuel bed is increased, the draft increases, and the percentage of CO_2 also increases. Finally a point will be reached at which the CO_2 does not increase further as the thickness of the fuel bed and the draft increase. The draft and fuel bed thickness to give this CO_2 reading represent the proper values for the given load on the boiler, under which the suggested changes in operating conditions have been made. This process should then be repeated for a number of different loads on the boiler. Upon doing this it will be found that with a given thickness of fuel bed, certain more or less well defined limits of draft over the fire will give a maximum CO_2 reading. The draft then becomes the key for controlling the whole situation. If the load on the boiler is such as to require drafts between certain limits, then the thickness of fire which should be used is immediately known, provided there are no holes in the fire and the tubes and fire are clean. These latter

conditions will be indicated by the differential draft gage, Fig. 4, readings of which should also have been taken during the tests when the tubes were known to be clean and the fire in good condition. A table or chart should be laid out for the use of the fireman, which, as soon as the approximate draft necessary to maintain boiler pressure is known, gives the thickness of fire to be carried and the corresponding differential draft gage reading. If the furnace draft and thickness of fire are correctly maintained and the differential is then too low, it indicates either that the fire is dirty or that some of the baffling has fallen. A too high reading of the differential indicates that there are holes in the fire, or that soot is clogging the passages through the tubes.

The thickness of the fire should not be left to the judgment of the fireman, but definite marks should be placed on the inside door liners, or at some points where they may be seen. In any case, it should be thoroughly understood that the coöperation of the fireman is necessary, and unless the fires are kept clean, and the firing is done in such manner as to maintain a uniform fuel bed without holes the other precautions suggested are useless.

Since air leakage through the setting tends to increase as the draft increases, it is good policy to run on the minimum draft which will carry the load without pressure drop. The CO_2 readings are a direct indication of the total loss due to both excess air and to air leakage when taken just below the damper. A curve * is presented in Fig. 7 which has been plotted from flue gas readings when burning Illinois slack on a chain grate. It gives the percentage of excess air represented by different percentages of CO_2 in the gas. From this curve it may be seen that 12 per cent of CO_2 represent about 35 per cent excess air. This is the maximum CO_2 reading obtainable with this coal when burned on grates of approximately 93 per cent grate efficiency without danger of incomplete combustion and a corresponding loss due to carbon monoxide. If this value is not exceeded, it will not be necessary to analyze for carbon monoxide and the determination for CO_2 is sufficient.

It has been mentioned in a preceding paragraph that the proper position for the sampling tube is at a point where the hot gases leave the heating surfaces for the last time. The reason for this may now

* Kratz., A. P., "A Study of Boiler Losses." Univ. of Ill. Eng. Exp. Sta., Bul. 78, p. 33, 1915.

be made clear. The CO_2 in the sample at this point is an indication of all the excess air and leakage which has diluted the gas and absorbed heat which should have gone into the water. After the gases leave the heating surfaces there is no longer any chance of heat being absorbed and it is not important, so far as efficiency is concerned whether it is lost in a small amount of gas at a high tem-

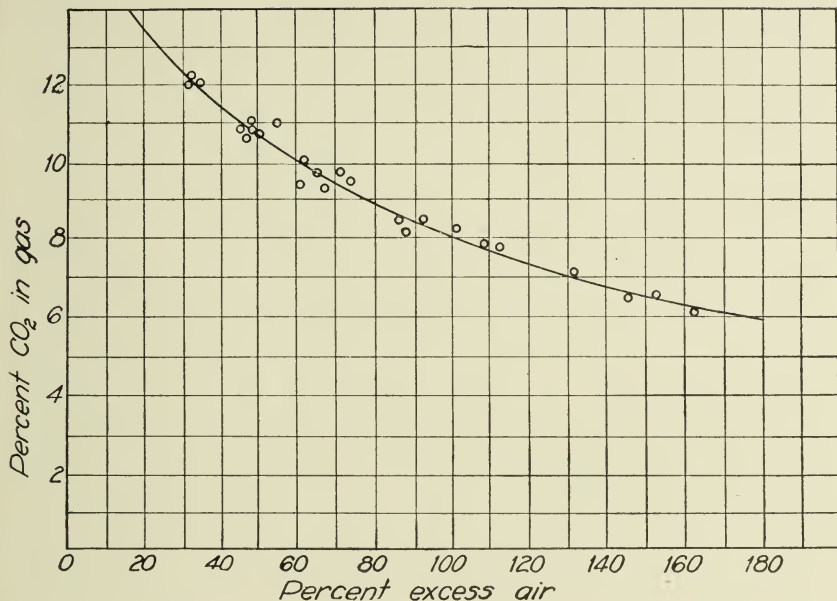


FIG. 7. CURVE SHOWING RELATION BETWEEN EXCESS AIR AND CO_2 IN FLUE GAS (See "A Study of Boiler Losses," Univ. of Ill. Eng. Exp. Sta., Bul. 78, 1915.)

perature, or in a large amount of air and gas at a lower temperature. Any air leakage beyond this point, therefore, does not lower the efficiency. The harmful effect, however, is shown on the capacity. It not only adds its own bulk to the gases the chimney must carry, but also, due to its cooling effect on the hot gases, lessens the draft available to produce the flow. In many cases the mere stopping of the leaks in setting and breeching has enabled boilers to carry overload, while previously it had been impossible to obtain rated capacity.

The draft should be controlled by means of the dampers at the flue, and not by the ashpit doors. Closing the ashpit doors prevents air from going through the fuel bed, causes canker and hot grates,

and also increases the air leakage loss. Each boiler should be equipped with a separate damper and the position of maximum and minimum damper opening should be determined. The damper should then be operated between these limits. The points of maximum and minimum opening should be found by noting the reading of the draft gage while the damper is moved from one extreme position to the other. These points of maximum and minimum draft gage reading may not coincide with the points at which the damper is mechanically open or closed. A position will usually be found at which the draft is maximum, and a further opening of the damper will not change the reading. It may also be found that the damper can be opened quite appreciably before the draft gage begins to read. In many plants of large and medium size automatic draft control has proved economical and it is also of advantage in maintaining constant steam pressure. If automatic control of the draft is used, it is important to have the damper adjusted for the range of travel determined by experiment as suggested, so that the draft will be proportional to the opening. An automatic damper regulator, when used, should preferably be of the type which responds to small decreases or increases in steam pressure by causing a corresponding movement of the damper, and not of the type which either completely opens or completely closes the damper in response to small decreases or increases of pressure. If there are several boilers in the plant, the best plan is to adjust the individual dampers so that each boiler is carrying its share of the load under the most economical draft, and then, if the total load changes, to regulate with a master damper in the main flue.

Loss Due to the Presence of Combustible in the Ash

The loss due to partly burned coal in the ash should not, with very careful handling of the fire, exceed more than about three per cent of the heat value of the coal. Excessive carbon in the ash with stoker fired furnaces usually indicates too rapid feed for the rate of combustion used. In hand fired furnaces it may indicate that the grate openings are too large for the size of coal used or that the fire is worked too much, or both. So far as possible the fire should be operated without much working except at times of cleaning. Too much working does two things; first, it shakes the green coal down into the ash and allows it to pass through the grate bars, and

secondly, it brings the ash up into the hot part of the fire where it fuses and causes clinker. Partly burned coal is fused in with the clinker and is lost when the clinker is removed, and the coal which is shaken through the grates during the additional working required to remove the clinker adds further to the loss. The possible loss due to firing green coal into holes in the fire and thus permitting it to pass through the grate has not been considered in detail because it is obvious that the holes should be filled up by leveling the fire before adding a fresh charge of green coal. In working a fire, it should be sliced from the bottom in such a manner as to avoid or minimize the possibility of forcing ash up into the fuel bed. This applies to stoker firing as well as to hand firing.

Loss Due to the Presence of Carbon Monoxide in the Flue Gases

Carbon monoxide is formed if too thick a fire or an insufficient draft is used. With central bituminous coals there is little possibility of large loss from this source if the CO_2 reading is not more than 12 per cent.

Loss Due to Soot

The largest part of the loss due to smoke does not result from the fact that the particles of carbon floating in the gas stream have passed out before giving up their heat value, but it comes from the deposit of soot on the tubes. The actual heat value of this deposit of soot is small when compared with the amount of coal fired in producing it, but its power of preventing the heat in the gases from reaching the tubes and being absorbed is a factor of considerable importance. Soot makes an excellent heat insulator, about five times as effective as asbestos. Under normal working conditions and with the normal amount of air, the temperature of the gases leaving the boiler should be somewhere near 550 degrees F. If they leave at a much higher temperature and the fire and drafts are normal, it signifies that the tubes need blowing. The soot deposited on the heating surfaces is keeping the heat in the gas from reaching the water and the gases consequently are not cooled. Where automatic blowers are installed the tubes should be blown every four or five hours. In all cases they should be blown at least once for every shift. A pyrometer placed at the point where the gases leave the tubes for the last time will give a fairly good indication of their condition, provided of course that low temperature is not due to excess air.

Loss Due to Moisture in the Coal and Air

The loss due to moisture in the air is very small and need not be considered. That due to moisture in the coal may be larger. The coal may carry 13 or 14 per cent of moisture, and the heat required to evaporate this must be furnished by the coal itself, thus decreasing the amount available to heat water in the boiler. Fine coal tends to pack if fired dry. This prevents the proper amount of air getting to the fuel, and results in the formation of carbon monoxide and in cold fires. Sometimes very dry coal burns out unevenly, and will not stay on the grates without allowing holes to form. For these reasons, it is advisable to wet down the smaller sizes of coal just before firing because the other losses mentioned are greater than that due to the water. With larger sizes wetting is not necessary and is not advisable. This, however, must be decided for each individual plant. In no case should more water be added than is absolutely necessary.

Loss Due to Heat in the Escaping Gases

Every pound of flue gas passing up the stack represents a loss of about .24 heat units per degree F. above the temperature of the steam in the boiler. This loss cannot be entirely eliminated. For plants operating on natural draft, a temperature of about 500 degrees F. is required in the stack to produce the draft necessary to operate the boilers at full capacity. An average of 550 degrees F. is good practice. For forced draft and four-pass boilers, it may run lower than this temperature. An indicating pyrometer should be used on each boiler and if the temperature in the flue becomes abnormally high it may be accepted as an indication of an excessive deposit of soot upon the tubes or of a draft greater than is necessary for the load.

Loss Due to Radiation

Uncovered surfaces and other surfaces which are too hot to touch without discomfort represent a serious loss of heat. This loss can be decreased by covering the setting as previously suggested.

12. *Significance of Smoke.*—Smoke, depending upon its cause, may or may not indicate a loss in efficiency. The loss is largely due to the soot deposit, and not to the heat value of the fine particles of floating carbon. The three principles of smokeless combustion

have already been stated. The question concerning whether there is sufficient air for combustion can be answered with the CO_2 analyzer. If the CO_2 reading is normal and smoke still appears, the trouble is due either to a faulty mixture of the air and combustible gases, or to a too small combustion chamber. Increasing the air supply may decrease the smoke, but it also decreases the efficiency. In this case smokeless combustion does not indicate high efficiency. If the fire is hot and there is much oxygen in the gas, together with high carbon monoxide, the trouble is due to poor mixing of the gas and air over the fuel bed. Mixing piers or arches will eliminate the smoke which in this case is an indication of loss of efficiency. If the fire is white hot, and the CO_2 normal, without any indication of carbon monoxide in the gas the trouble is due to a too small combustion chamber. In most plants this is the cause of smoke, and in such cases it does not indicate poor furnace efficiency. The loss is due to soot rather than to smoke.

13. *Methods of Hand Firing.*—There are two general methods advocated for hand firing, (1) Coking, (2) Spreading. The first involves the placing of a considerable amount of green coal on some convenient part of the fuel bed where the heat will pass into it and will slowly distil the volatile gases. These gases then mix with air above the bed and in passing over the white hot bed are burned before they reach the cold surfaces. The method usually adopted is to pile the green coal at the front of the bed. After 10 or 15 minutes, during which the coal has become well coked, this pile is broken up and spread over the back part of the fuel bed, and a fresh charge is piled at the front. This method accomplishes satisfactory results so far as smokeless combustion is concerned, but it does not promote efficiency. The keynote of efficiency lies in the maintenance of a uniform fuel bed, while with the coking method of firing the bed burns unevenly. The bed is usually too thick at the front, and burns out and develops holes at the rear, and although it is less liable to form clinker, this practice is not to be recommended as highly as some form of spreading.

In the spreading method, small quantities of coal are fired at frequent intervals. In alternate spreading, a thin layer of coal is spread on one side of the furnace. As the gases distil, they mix with the air, and the white hot surface on the other side maintains the

mixture at the ignition temperature. After a period of about five minutes, when the distillation is complete, another charge of fresh coal may be spread on the other side of the bed. By this method the fire may be kept in a more nearly uniform condition than by coking. Where the coal is spread over any considerable area, however, there is still a tendency for the resistance at different parts to vary, and for holes to develop.

The best method is to fire very often and in small quantities. Holes should not be permitted to develop; to prevent holes, small amounts of coal should be placed on the thin parts of the bed. Thin places may be recognized from the fact that they appear brighter and hotter than the rest of the bed. This method requires more attention on the part of the fireman, but it pays in the long run. It is possible to maintain a uniform bed for long periods without barring or working the fire. Where the coal is fired in small quantities, the volume of combustible distilled at one time is small and may be easily consumed over the hot part of the fuel bed without forming smoke.

In any case, in hand firing, it is necessary that some auxiliary air be taken in over the fuel bed for several minutes immediately after firing. This should be admitted across the fire close to the surface of the fuel bed, preferably from the front through auxiliary dampers in the fire door, which should have an area of at least four square inches per square foot of grate surface. This admission of air may be accomplished either automatically or under the control of the fireman. The automatic device opens small supplementary dampers when the fire door is opened, and then closes them gradually after the door is shut. The time of closing is usually about three minutes. The same result can be accomplished by the fireman regulating the dampers in the fire door by hand. In some cases the use of a steam jet immediately after firing has proved advantageous, since it not only carries in the air necessary for the combustion of the volatile gases, but also serves thoroughly to mix the air and gases.

14. *Stoker Firing*.—It is not within the scope of this discussion to give detailed instructions for the use of different types of stokers. All the statements, however, concerning tight settings, determination of proper fuel bed thickness, draft, soot, etc., apply to stoker firing as well as to hand firing. Most stokers accomplish one

prime requisite for good combustion, *i.e.*, a uniform supply of coal and air, but they require as intelligent attention as does hand firing. Stokers should be inspected regularly to see that all ledge plates, baffles, and other devices designed to decrease air leakage are performing their functions properly. The grate should be kept uniformly covered with fuel and the rate of feed adjusted so as to minimize the amount of unburned coal carried over into the ashpit. The chain grate stoker is probably more generally used for Illinois coal than any other type, and it has usually proved satisfactory. It is used largely for burning slack, or screenings, and for this purpose a fuel bed of about six inches gives the best results, particularly when natural draft is used. Detailed instructions for the operation of any particular type of stoker may be obtained from the company building it.

IV. FEATURES OF BOILER INSTALLATION IN RELATION TO FUEL ECONOMY

15. *Boiler Settings*.—The boiler setting consists of the foundation and such parts of the furnace and gas passages as are external to the boiler shell. The setting must furnish a proper support for the boiler and at the same time provide the necessary passages for the products of combustion as well as a pit for the ashes.

Foundation

A good solid foundation resting on a firm footing is absolutely necessary to insure a boiler setting which will remain tight and free from any tendency to crack. The depth of the foundation and the width of the footings necessary for a given installation depend upon the character of the soil. In the case of good solid soil capable of supporting heavy loads, the excavation need not be made very deep, but where the ground is soft it is well to excavate the entire space occupied by the setting and to construct a bed of concrete about two feet thick upon which the walls may be supported.

When boilers are supported on steel columns, as is usually the case with water tube boilers and as is desirable for fire tube boilers also, the footings at the base of the columns must be enlarged, since with such means of support the loads are concentrated and not distributed as in the case of horizontal return tubular boilers supported by a series of lugs resting on the walls of the setting. In general, the foundation for all types of boilers should be very rigid; a weak foundation will always cause the setting to crack no matter how well the brick in the walls may be set. Weak foundations may, furthermore, tend to produce severe stresses at pipe connections to the boiler which are likely to cause trouble.

Side and End Walls

The side and rear walls are supported upon the foundation and in the older designs of settings a two-inch air space is generally provided in these walls. In many of the newer types of setting, however, this air space has been omitted. As a result of a series of experiments made by the United States Geological Survey, it has been found that the two-inch air space provided in the walls of boiler settings has

practically no effect in preventing the flow of heat from the interior of the setting. As a matter of fact the radiation losses for a wall with an air space are greater than those for a solid wall. In order to strengthen the side walls, buck-stays held together by long bolts are used. The furnace, the bridge wall, and all parts of the side and rear walls including the back arch which are exposed to the hot gases must be lined with high grade fire brick capable of withstanding the high temperatures. The fire brick should be backed with hard, well burned, red bricks laid in a high grade mortar. All arches, piers, and wing walls which may form a part of the combustion chamber should be made entirely of fire brick.

Settings for Horizontal Return Tubular Boilers

In order to use soft coal economically it is desirable to obtain as complete combustion as possible. Complete combustion also means elimination of smoke. To obtain proper combustion sufficient air must be introduced into the furnace to supply the necessary oxygen. The air thus introduced must mix thoroughly with the gases given off by the burning coal and the mixture thus obtained must be kept at a high temperature until the process of combustion is completed. The old

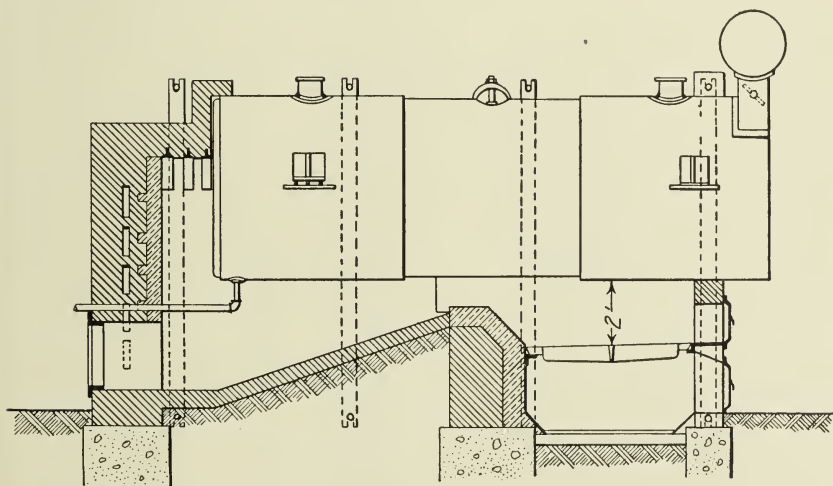


FIG. 8. HARTFORD SETTING FOR RETURN TUBULAR BOILERS

This setting does not satisfy the conditions for smokeless combustion. In fact it is, for Central Western coals, very unsatisfactory and should not be used.

The setting shown in the above figure is no longer used or approved by the Hartford Steam Boiler Inspection and Insurance Co. This company has made very material changes in the design of their horizontal return tubular boiler settings in recent years.

standard setting for return tubular boilers (shown in Fig. 8) is frequently used, but it does not satisfy the conditions stated and for this reason should not be used when smokeless combustion is required. In recent years several types of settings have been devised which if properly fired make possible the satisfactory combustion of bituminous coal.

A type of horizontal return tubular boiler setting which has given good results with soft coals is shown in Fig. 9. It was originated and perfected by the engineers associated with the Department of Smoke Inspection of the City of Chicago and is generally recommended for boilers operating at a steam pressure of sixty pounds or more. This setting differs from that illustrated in Fig. 8 in that a series of arches are constructed over the bridge wall and in the combustion chamber. A double-arch rests on the bridge wall and on a suitable pier built up between the bridge wall and a single span deflection arch, the latter being located from two to three feet back of the bridge wall. The highest point of this deflection arch is at the elevation of the top of the bridge wall or somewhat below it. So as to prevent the gases from passing over the arches bulkheads extending up to the boiler are constructed above them.

It is evident from this brief description that the gases in passing from the grate over the bridge wall are divided into two separate streams by the central pier supporting the double-arch. In going through the retorts formed by the double-arch and the side walls of the setting the gases are thoroughly mixed and at the same time are subjected to high temperatures. Having passed through the retorts the gases are compelled to change their direction of travel so as to pass under the deflection arch back of the bridge wall, thus promoting further mixing and thereby insuring proper combustion. The setting is also provided with the usual panel door for the admission of air over the fire. The steam jets shown extending through the furnace front are generally considered standard equipment and it is recommended that they be freely used after each firing.

The arches used in connection with the setting shown in Fig. 9 produce a side pressure on the walls, and in order to prevent bulging and cracking of the walls additional buck-stays and tie rods should be installed. The floor of the combustion chamber is subjected to high temperatures and for this reason should be paved with second-grade fire brick laid on edge.

According to Osborne Monnett* the following general proportions should be satisfied in order to obtain satisfactory service with this type of setting.

- (1) The free area through the double-arch above the bridge wall should be made equivalent to at least 25 per cent of the grate area.
- (2) The area from the back of the bridge wall to the deflection arch should be at least 45 per cent of the grate area.
- (3) The area under the deflection arch should be at least 50 per cent of the grate area.

For convenience of reference the dimensions indicated in Fig. 9 for various sizes of boilers are given in the table presented with the illustration. These dimensions were obtained from a report submitted by the Standards Committee at the eleventh annual convention of the Smoke Prevention Association.

There are several patented settings in which the gases are maintained at a high temperature and are thoroughly mixed by the use of piers and wing walls in place of the arches shown in the setting of Fig. 9. Experience seems to indicate that the temperature in the combustion chamber of such settings is sufficiently high to promote proper combustion, and furthermore it is claimed that they burn coal with good economy and are cheaper to construct than the double-arch setting.

Settings for Water Tube Boilers

A large number of hand fired water tube boilers of the horizontal type designed for the use of soft coal are installed with what is generally called the standard vertical baffling. This form of baffling compels the gases to pass across the tubes, thus producing a rather short flame travel in the first pass and rendering complete combustion impossible. In order to improve combustion in hand fired water tube boilers of the horizontal type when burning soft coal, it has been demonstrated by the Chicago Department of Smoke Inspection that the setting should be so arranged as to fulfill the following specifications: †

* "Hand Fired Furnaces for Water Tube Boilers—I." *Power*, Vol. 40, p. 264, August 25, 1914.

† *Ibid.*

- (1) Some provision must be made so that the bottom row of tubes will absorb some heat directly from the fire. This is accomplished by the use of T-tiles, thus exposing the bottom row of tubes to the fire for a short distance from the front header.
- (2) Over the bridge wall and for some distance back of it a high temperature zone, through which the gases and air pass, must be provided. This zone is obtained by using box-tiles around the bottom tubes. The box-tiles extend from the end of the T-tiles to a point several feet in front of the back header. The area provided between the bridge wall and the box-tile should be made equivalent to 25 per cent of the grate area.
- (3) In order that the gases and air will thoroughly mix, a deflecting arch is provided a short distance back of the bridge wall. The distance between the arch and the bridge wall should be such that the area obtained between them is equivalent to 40 per cent of the grate area. The height of the arch must be sufficient so as to provide an area underneath it equivalent to 50 per cent of the grate area.
- (4) As in the case of the horizontal return tubular boiler settings, excess air is provided through the panel doors in addition to a siphon steam jet located above the fire doors.

When water tube boilers are very wide, it may be necessary to construct the deflection arch mentioned in (3) in two or three spans. These spans should be supported on suitable piers in order to relieve the strain on the side walls. In case the area over the bridge wall is in excess of 25 per cent of the grate area, the desired area may be obtained by introducing piers upon the bridge wall opposite the spans in the deflection arch. Due to these piers the gases and air will be more thoroughly mixed, thus promoting combustion.

In water tube boilers equipped with horizontal baffles it generally happens that there are parts of certain tubes which are not acted upon effectively by the gases. This is due to the fact that the gases become trapped in the corners as shown at A in Fig. 10 and become inert. Such a condition can be improved with a gain in the efficiency of the boiler, by providing openings approximately one inch wide in alternate rows of the tile B, Fig. 10.

One of the most serious defects found in brick settings is air leakage. The fire brick used on the interior of the setting must be selected with great care as the life of the setting very largely depends upon the quality of these bricks as well as upon the workmanship in laying them. Generally the arches used in settings cause more trouble than

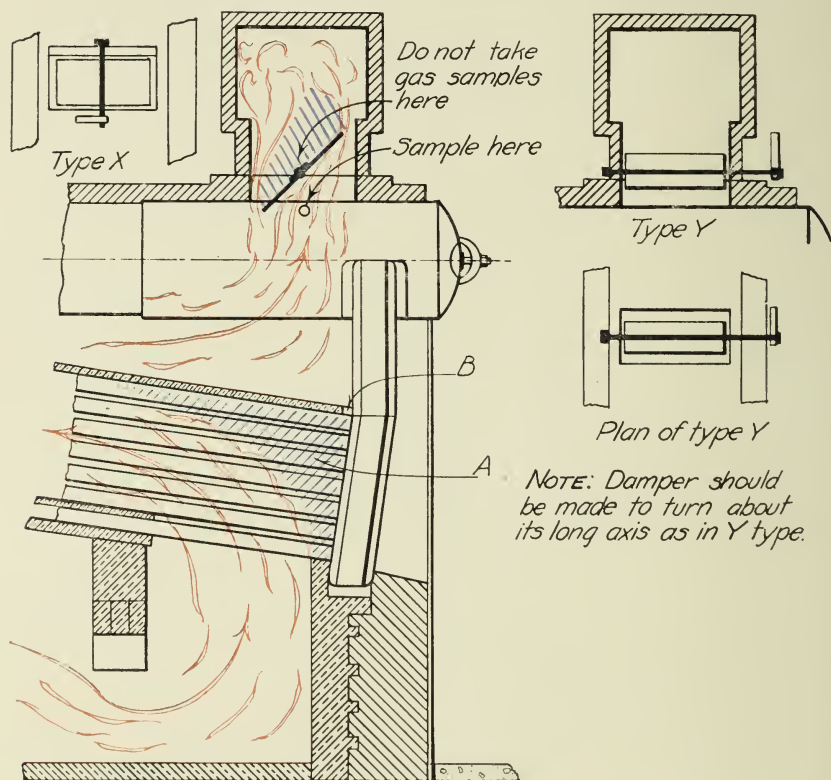


FIG. 10. SKETCH SHOWING EFFECTS OF BAFFLING AND DAMPERS IN CAUSING POCKETS AND EDDIES IN THE FLUE GAS STREAM

Defects in Settings

any other part of the setting. In some cases arches fail because of the use of a grade of brick not suited to the purpose, but more frequently failures are due to poor workmanship in laying the bricks. Air leakage through the setting can be reduced by pointing up the brick work in the proper manner and by covering the entire setting with an

insulating material, as for example a high grade of asbestos or magnesia covering. The exposed parts of the shell of horizontal return tubular boilers and of the steam drums of water tube boilers should be covered with an 85 per cent magnesia covering two or three inches thick. The outer surfaces of all insulating materials should be finished off with a thin coating of hard cement or covered with canvas and painted. If the walls of the setting are constructed with air spaces these spaces should be filled with sand or ashes. The baffles on the interior of the setting should be kept tight so that the gases cannot be by-passed through the heating surfaces. All steam and water leaks around a boiler should be stopped immediately since water coming in contact with heated brick work is likely to cause rapid disintegration of the brick. The setting should be so constructed that the boiler is free to expand without affecting the brick work.

V. INSTALLATION FEATURES AFFECTING DRAFT CONDITIONS

16. *Stacks and Breechings*.—The purpose of a stack is, of course, to supply air to the fuel which is burning on the grates of the boiler furnace and then to remove the flue gases which are formed after they have passed over the boiler surfaces and given up most of their heat to the water and steam in the boiler. The stack may waste coal if the fireman allows it to supply too much or too little air, or if he allows the flue gases to leave the boiler at too high a temperature. Most stacks supply too much air so that a large amount of heat is carried away in the unnecessarily large volume of flue gases formed when this air passes through the fuel bed, where it not only serves to burn the coal but also takes up heat.

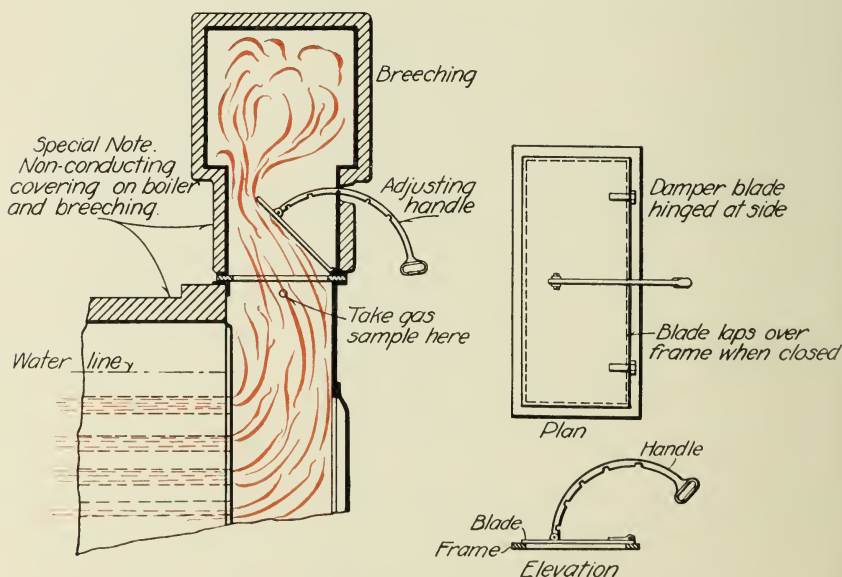


FIG. 11. AN APPROVED FORM OF HINGED DAMPER

The Stack Damper and Its Use

In order to control the amount of air and flue gas passing to a stack, a damper (Figs. 10 and 11) should be installed at the point where the flue gas leaves each boiler. This damper should fit tight

and true and should move easily. An approved form of damper, which is tight fitting, is shown in Fig. 11. It should have a free opening about 25 per cent greater than the area through the tubes. Long narrow dampers are to be avoided wherever possible. For water tube boilers the damper opening should be about 0.25 of the grate area. The damper must be opened only enough to permit the stack to supply the right amount of air to burn completely the fuel fired. When the demand for steam increases, more coal must be burned and the damper must be opened wider in order to supply more air. The air supply should *not* be controlled by opening and closing the ashpit doors, which should stand wide open practically all the time. If the stack is not controlled by the damper, it will always exert its full power on the setting which means that the tendency for air to leak in at any cracks and joints will be as great at half load as at full load, and even with the ashpit doors closed this leakage would be unchanged if the stack damper remained open.

From what has been stated, it is evident that a stack must be capable (at full damper opening) of supplying all the air that the boiler may require when burning coal at the highest rate (pounds per hour) necessary for the maximum load. At all other rates of burning coal the damper must be partly closed, and in many plants, since the stack is too powerful (supplies too much air) even for the highest rate of burning coal, the damper must never be fully opened; otherwise too much air will pass through the grates and fuel will be wasted.

In order that the approximate capacity of a stack may be checked against the load it should carry, Table 3 has been arranged in convenient form for ready reference. Thus, if a certain boiler plant is burning 2,800 pounds of coal an hour at its maximum capacity and the stack is 100 feet high, the diameter should be 60 inches,

Table 3 is a modification of William Kent's stack table and is reliable for the ordinary rates of combustion with bituminous coals. The values in the table give the pounds of coal burned per hour. With coal of fair grade it is necessary to burn about five pounds per boiler horse-power, but with low grade bituminous coal it is necessary to burn from six to eight pounds per boiler horse-power. For example, in the boiler plant already considered, burning 2,800 pounds of coal an hour, a stack 100 feet high and 60 inches in diameter would provide only for 400 boiler horse-power, if a poor grade of middle western coal was used requiring seven pounds per boiler horse-power.

TABLE 3
STACK SIZES BASED ON KENT'S FORMULA

Diameter Inches	Area Square Feet	HEIGHT OF STACK IN FEET										Side of Equivalent Square Stack, In.	Diameter Inches
		50	60	70	80	90	100	110	125	150	175		
		POUNDS OF COAL BURNED PER HOUR											
33	5.94	530	575	625	665	705	745	30	33
36	7.07	645	705	760	815	865	910	32	36
39	8.30	775	845	915	980	1040	1095	1145	1225	35	39
42	9.62	915	1000	1080	1155	1225	1290	1355	1445	1580	38	42
48	12.57	1230	1345	1450	1555	1650	1740	1825	1945	2130	2300	43	48
54	15.90	1590	1740	1880	2010	2135	2245	2360	2515	2755	2975	48	54
60	19.64	2000	2185	2365	2525	2680	2825	2965	3160	3460	3740	54	60
66	23.76	2450	2685	2900	3100	3290	3470	3640	3800	4245	4590	59	66
72	28.27	2955	3230	3490	3735	3960	4175	4380	4670	5115	5525	64	72
78	33.18	3500	3830	4140	4425	4695	4950	5190	5535	6060	6550	70	78
84	38.48	4090	4480	4840	5175	5490	5785	6070	6470	7090	7655	75	84
		HEIGHT OF STACK IN FEET											
		100	110	125	150	175	200	225	250				
		POUNDS OF COAL BURNED PER HOUR											
90	44.18	6690	7015	7480	8195	8850	9465	10040	10580	80	90		
96	50.27	7660	8080	8565	9380	10135	10835	11490	12115	86	96		
102	56.75	8695	9120	9720	10650	11500	12295	13045	13750	91	102		
108	63.62	9795	10270	10950	11960	12960	13850	14695	15490	98	108		
114	70.88	10960	11495	12255	13425	14500	15500	16440	17330	101	114		
120	78.54	12190	12785	13630	14930	16130	17240	18285	19275	107	120		
126	86.59	13485	14145	15080	16515	17840	19070	20230	21325	112	126		
132	95.03	14850	15570	16605	18185	19645	21000	22275	23480	117	132		
144	113.10	17770	18630	19865	21760	23505	25130	26655	28090	128	144		
156	132.73	20950	21965	23420	25655	27710	29625	31425	33120	138	156		
168	153.94	24390	25575	27270	29870	32270	34495	36590	38565	150	168		

“Draft” is in Reality a Pressure

It must be remembered that air enters the ashpit, or rushes through the open fire door, or through any cracks or crevices in the setting or breeching because the surrounding outside air is always

heavier than the hot flue gas in the stack and setting, and hence exerts an inward pressure at all points. The so-called "draft" over the grate as shown by a draft gage (Figs. 3 and 4) is an indication of this difference in pressure or tendency for the outside air to crowd its way into the furnace and boiler setting. In order to understand why this tendency exists and why draft is a true *pressure* and not a suction

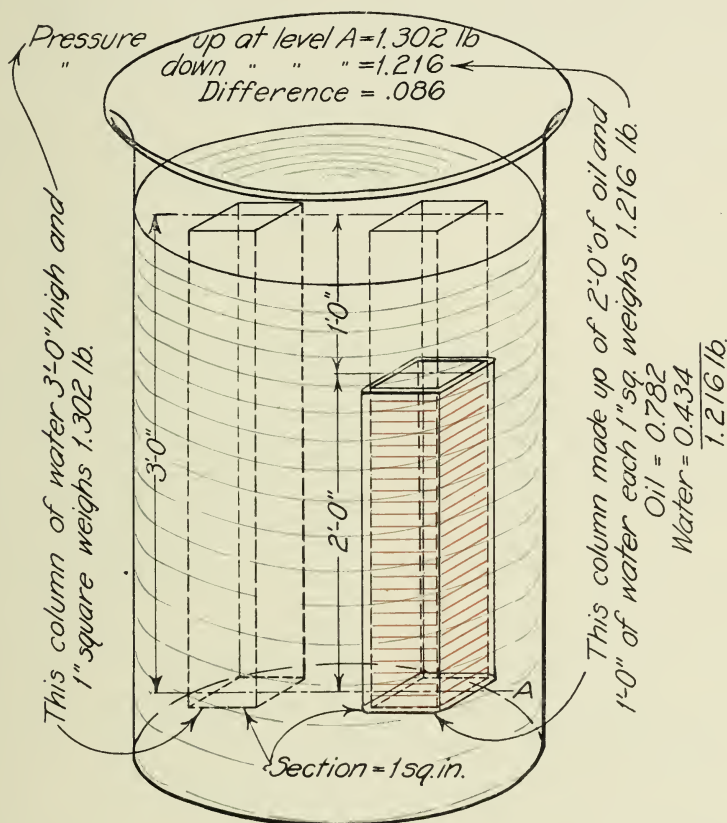


FIG. 12. ISOMETRIC SKETCH ILLUSTRATING THE PRINCIPLE THAT LIGHT FLUIDS OR GASES ARE PUSHED UPWARD WHEN IN CONTACT WITH HEAVIER FLUIDS OR GASES

In this case the lighter fluid, oil (shown in red), is pushed up by the heavier fluid, water (shown in green). The force pushing the oil up the tube is 0.086 pounds per square inch.

refer to Fig. 12. It will be evident that, since the column of water two feet high weighs more per square inch than a similar column of oil, the water will *push* the oil up the tube in the same way that the

cold outside air pushes through the grates of a boiler furnace and forces the hot flue gas up the chimney. If there is a fire burning on the grate the action is continuous, and outside air will continue to

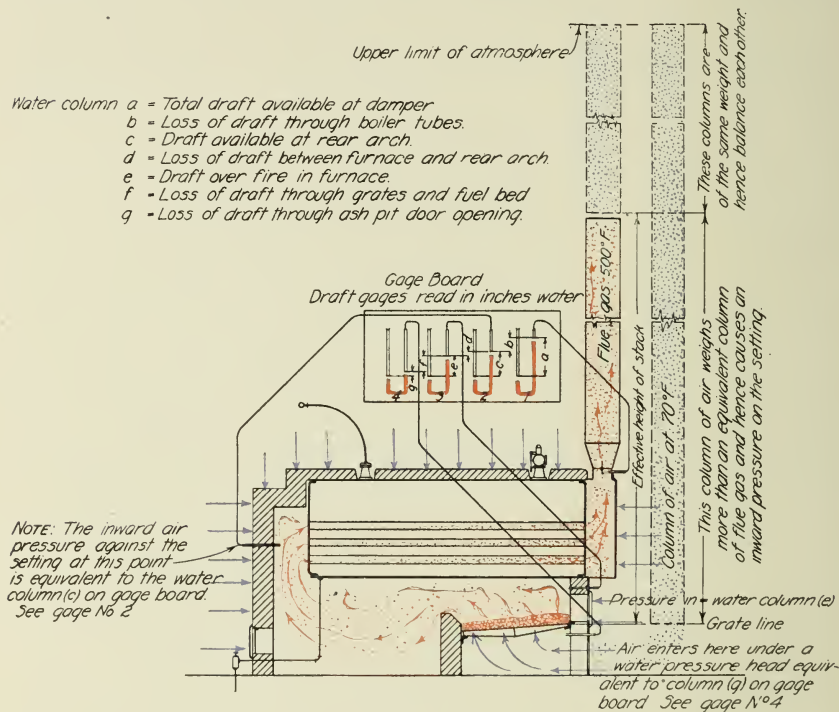


FIG. 13. SKETCH SHOWING VARIATIONS IN DRAFT AT DIFFERENT POINTS AND INDICATING TENDENCY TOWARD AIR LEAKAGE

enter the ashpit (Fig. 13) and push its way through the bed of fuel on the grate, thus promoting the combustion of the fuel.

Air Leaks Affect the Draft and Waste Coal

If cold air leaks into the setting at any point, it will result in two forms of fuel waste. First, it will cool the gases in the setting and in the chimney and will make the draft less. This may make it difficult to burn the fuel properly. Secondly, the air which has leaked in must be warmed up, thus taking heat away from the boiler and wasting it through the chimney, and finally this air will so increase the volume of flue gas that it may be difficult for the chimney to handle the increased volume of flue gas even with the damper wide open.

Breechings for a Battery of Two or More Boilers

Many breechings serving more than one boiler are condemned as being too small because so much unnecessary air is leaking into the various settings that the breeching cannot handle both the leakage and the necessary flue gas. By systematically stopping all the leaks such a breeching will often easily handle the flue gases resulting from the minimum air supply actually required for burning the fuel. Breechings should be at least from 10 to 15 per cent greater in area than the stack to which they connect.

The individual boiler dampers in the throat or uptake connections opening into a breeching should fit accurately and close tightly, otherwise it will be impossible to prevent cold air from entering the main breeching through the damper of a "dead" boiler. This will often seriously affect the operation of all the other boilers by "checking" the draft of the stack which serves the boilers connected to this breeching.

Breechings should be as short and straight as possible, and should have no sharp angles around which the flue gases may swirl and eddy in their passage to the stack. The bad effect of sharp angles is shown in the stack connection marked "B" in Fig. 14. The method of correcting this difficulty is shown at "A" in the same figure. Breechings should be covered with a good heat insulating material or lined with a refractory brick or vitrified material.

All boiler dampers should be "calibrated," that is, should have the operating lever or chain so marked and set that the draft for boiler No. 1, nearest the stack (Fig. 14), will be no greater than for boiler No. 3, farthest from the stack, when both boilers are clean and have the same thickness of fuel bed. To accomplish this result it may be found that the damper on the nearest boiler must be nearly closed most of the time. If all dampers are set at the same angle without regard to their location with reference to the stack, too much air will go through the nearest boiler or the farthest boiler will get too little air and suffer a loss in capacity.

Conditions Under Which a Stack Will Operate Economically

If fuel is to be used economically, the stack must supply the furnace with just enough air to burn the fuel completely. This can only be done when the following conditions are observed:

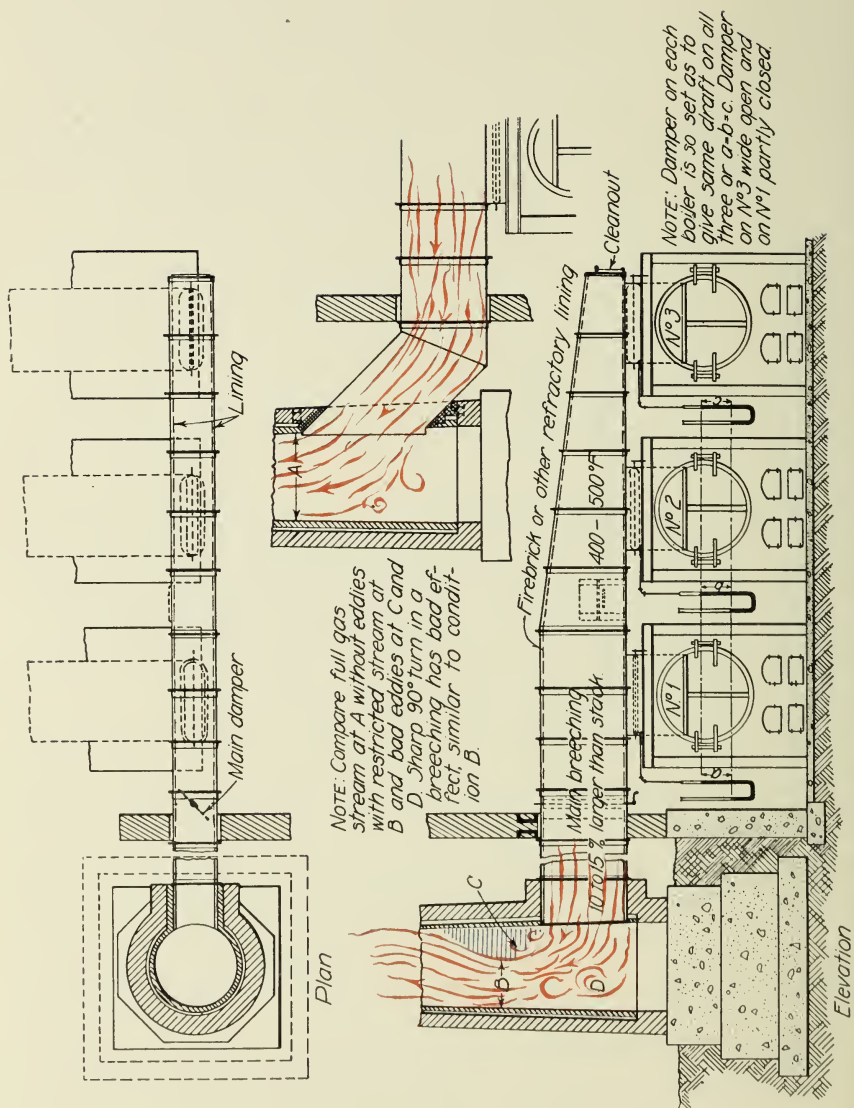


FIG. 14. STACK AND BREECHING CONNECTIONS FOR A BATTERY OF THREE BOILERS

- (1) The setting must be made air tight.*
- (2) All doors and door frames opening into setting and breeching must be made to fit air tight.
- (3) The breeching and stack should likewise be made air tight and should be well insulated to prevent heat loss from the flue gases so that all the heat in the gases may be available for creating draft.
- (4) The air used for burning the fuel should *all* enter through the ashpit, except a limited and carefully regulated air supply which should be admitted through the fire door after firing fresh coal.
- (5) When natural draft is employed, the control of the air should be accomplished by operating the stack or breeching damper according to the rate of burning coal and never by opening and closing the ashpit doors.

* A candle flame is commonly used to detect air leaks into a setting since it will be drawn into any crevice through which air is entering.

VI. FEED WATER HEATING AND PURIFICATION AS FACTORS IN FUEL ECONOMY

17. *Feed Water Purification.*—The majority of waters used for boiler feeding purposes contain more or less impurities which are deposited in the boiler. Such deposits of foreign matter tend to decrease the evaporative capacity of the boiler and, if they are not removed, will frequently cause overheating of tubes and sheets. To overcome these difficulties the impurities in the feed water should be removed before feeding into the boiler.

For convenience of reference, the impurities most often found in feed water and their effects upon the sheets and tubes if permitted

TABLE 4
IMPURITIES IN FEED WATERS, THEIR EFFECTS AND REMEDIES¹

Impurities	Effects	Remedies
1	2	3
Sediment, mud, clay, etc. Bicarbonates of lime, magnesia Sulphates of lime and magnesia	Incrustation and the formation of sludge	Settling tanks, filtration, blowing down. Blow down. Heat feed water. Treat by adding lime. Treat by adding soda. Barium carbonate.
Chloride and sulphate of magnesia Acid Dissolved carbonic acid and oxygen Grease Organic matter	Corrosion	Treat by adding carbonate of soda. Soda or lime. Heat feed water. Keep air from feed water. Add caustic soda or slacked lime. Filter. Iron alum as coagulant. Neutralize with carbonate of soda. Use the best of hydrocarbon oils. Filter. Use coagulant.
Sewage Readily soluble salts in large quantities Carbonate of soda in large quantities ²	Priming	Settling tanks. Filter in connection with coagulant. Blow down. Barium carbonate. New feed supply. If from over treatment, change or modify.

¹ "Steam," published by Babcock & Wilcox Company.

² May cause brittleness in plates. See Bulletin 94, Eng. Exp. Sta. Univ. of Ill., "The Embrittling Action of Sodium Hydroxide on Soft Steel," by S. W. Parr.

to enter the boiler are given in columns 1 and 2 of Table 4. In the last column of this table are given the usual remedies employed to

neutralize or to prevent to a certain degree the effects produced by the various impurities. Some of the impurities found in feed water cause the formation of scale on the sheets and tubes, others cause corrosion of the metal, and still others produce priming, or the carrying over of particles of water with the steam as the latter leaves the boiler.

18. *Treatment of Feed Waters.*—One of the best ways of determining the remedy to be applied in overcoming the injurious effects of the impurities contained in the feed water is to submit a sample of the water to a reliable chemist for analysis and prescription. After such an analysis has been made it is possible to ascertain which one of the following treatments should be applied, chemical treatment, heat treatment, or combined heat and chemical treatment.

Chemical Treatment

The chemical treatment of feed water involves the use of either the lime or the soda process or a combination of these two. The first of these processes in which *slacked lime* is used is well adapted for precipitating the bicarbonate of lime and magnesia contained in the feed water. In the soda process *carbonate of soda* or *caustic soda*, either separately or together, is used for converting the sulphates of lime and magnesia into carbonates or chlorides which may be disposed of by occasional blowing off. The combination of the lime and soda processes, however, is most frequently used. It is satisfactory for treating water containing sulphates of lime and magnesia, carbonic acid, or bicarbonates of lime and magnesia. In this process the sulphates are broken down by the use of sufficient soda, and the necessary lime is added to absorb the carbonic acid not taken up in the soda reaction.

Heat Treatment

The bicarbonates of lime and magnesia so often found in natural waters may be partially precipitated by preheating the feed water in some form of apparatus commonly called a heater. The sulphates of lime and magnesia, however, require high temperatures for complete precipitation and it is impossible to remove these impurities by the simple process of preheating in the ordinary heater using exhaust steam. Instead, live steam heaters and economizers are required for removing them.

Combined Chemical and Heat Treatment

Since preheating of feed water removes the carbonates of lime and magnesia, many water purification systems combine the chemical and heat treatments discussed in the preceding paragraphs, the chemical treatment being used merely for reducing the sulphates.

19. *Boiler Compounds*.—So-called boiler compounds are used rather extensively for treating feed water and no doubt in many cases the results obtained are satisfactory. According to reliable authorities the use of compounds is recommended for the prevention of new scale rather than for the removal of old scale. In general, no compound should be used until the proper advice has been obtained to insure the selection of the right compound for the particular feed water to be treated. In no event should the use of boiler compounds be regarded as a suitable substitute for regular cleaning and inspection.

20. *Feed Water Heaters*.—In any power plant of considerable size cold water should not be fed into the boilers, since all steam boilers are more or less seriously affected by the resulting unequal expansion and contraction. If cold water is forced into the boiler, the tubes of water tube boilers are very likely to become troublesome while in return tubular boilers the seams are liable to develop leaks. Furthermore the feed water cannot be converted into steam until its temperature is raised to the point controlled by the steam pressure, and to do that requires fuel. If the temperature of the feed water can be raised by means of heat which otherwise would be wasted, it is good economy to do so. The preheating of feed water also increases the steaming capacity of the boiler, because of the reduction in the amount of heat to be supplied by the boiler per pound of water evaporated. With certain types of feed water heaters a considerable portion of the scale forming ingredients are precipitated before the water enters the boiler, thus increasing the efficiency and capacity of the boiler as well as effecting a saving in the expense of cleaning out the boiler. In general, it may be stated that one per cent of fuel is saved for every eleven degrees rise in the feed water temperature, provided the heat producing this rise in temperature would otherwise be wasted.

In steam power plants there are two main sources of waste heat, the first being the exhaust steam of the various units, and the second the products of combustion which pass from the boiler to the chimney.

The heat contained in the drips from the high pressure piping system is also a source of loss in many small plants, although its extent is not great. Condensation in the high pressure system, which includes all piping under pressure practically equivalent to boiler pressure, is free from oil and should be returned to the feed water heater by means of pumps or traps. If desired the condensed steam may be returned directly to the boiler. In steam power plants, high pressure steam traps are generally used for automatically draining the condensation from the high pressure lines.

Exhaust Steam Heaters

Heaters using exhaust steam for heating the water may be either of the *open* or *closed type*.

An open heater is one in which the exhaust steam and water mingle, the steam in condensing giving up its heat directly to the water. In general an open heater consists of a shell the upper part of which contains a number of removable trays. The function of these trays is to break up the incoming feed water into thin streams or layers. In passing over the trays, the water mingles with the exhaust steam, and if sufficient steam is supplied temperatures as high as 210 degrees F. may result. It is evident that in an open heater only those scale forming ingredients which will precipitate below 210 degrees F. will be deposited in the heater. Below the trays, the heater is provided with a bed of coke or charcoal through which the water is filtered before the feed pump sends it into the boiler. The function of the coke or charcoal filter is to remove the precipitates and other suspended impurities coming into the heater. Open heaters should always be supplied with a suitable oil separator for removing any oil contained in the exhaust steam.

Closed Heaters

In a closed heater the exhaust steam and feed water do not come into actual contact with each other, the steam giving up its heat to the water by conduction. In one type of closed heater the exhaust steam surrounds tubes through which the water passes. In a second type, the steam passes through tubes which are surrounded by the water. Closed heaters are recommended only for installations where the feed water is free from scale forming ingredients, since there is a tendency for the tube in these heaters to become coated with a deposit of scale, thus materially decreasing the efficiency of the apparatus.

Advantages and Disadvantages of Exhaust Steam Heaters

The advantages of an open heater are as follows :

- (1) The feed water may reach approximately the temperature of the exhaust steam provided sufficient steam is supplied.
- (2) Scale and oil do not effect the transmission of heat.
- (3) The pressure in an open heater is low, practically atmospheric.
- (4) Scale and other impurities precipitated in the heater may easily be removed.
- (5) An open heater is well adapted to heating systems in which it is desired to pipe the returns direct to the heater.
- (6) The initial cost of an open heater is generally less than that of a closed heater.
- (7) With the open heater all the condensed steam is returned to the system.

The disadvantages of an open heater are as follows :

- (1) Some provision must be made for removing oil from the exhaust steam. In modern open heaters this is accomplished by effective oil separators attached directly to and forming a part of the heater.
- (2) "Sticking" or clogging of the back pressure valve may subject the open heater to excessive pressure.
- (3) If the feed water supply is under suction, open heaters may require the use of two pumps, one for hot and one for cold water.

The advantages of a closed heater are as follows :

- (1) The closed heater will safely withstand any ordinary boiler pressure.
- (2) Oil does not come in contact with the feed water.
- (3) It is the only type of heater which may be used in the exhaust main between a prime mover and its condenser.
- (4) Since it is customary to locate a closed heater on the pressure side of the feed pump, only one pump, and that for cold water, is necessary.

The disadvantages of a closed heater are as follows :

- (1) Scale and oil deposits on the tubes lower the heat transmission.
- (2) The temperature of the feed water will always be from four to eight degrees below the temperature of the incoming exhaust steam.
- (3) Scale in the tubes is removed with difficulty.

21. *Economizers*.—An economizer is an arrangement of vertical water tubes arranged in nests, located in the flue between the boiler and the stack. Its purpose is to heat the feed water. The adjacent nests of tubes are connected together by means of expansion bends. To prevent deposits of soot, the tubes are provided with automatic scrapers which are kept moving up and down by means of a suitable mechanism driven by a motor or a small steam engine. Since the temperature of the flue gases is generally about 550 degrees F., it is evident that considerable heat escapes through the chimney. In general, the load factor, the size of the plant, and the cost of fuel are factors which should be considered in determining the advisability of installing an economizer.

22. *Live Steam Heaters*.—Live steam heaters use steam at boiler pressure and, as mentioned in a preceding paragraph, are primarily intended for purifying the feed water. Such heaters are generally not installed unless scale forming impurities are found in the water. At temperatures less than 300 degrees F. the sulphates of lime and magnesia do not entirely precipitate; hence a feed water containing these impurities will not be thoroughly purified by preheating with exhaust steam at atmospheric pressure. Reports of tests tend to show that live steam heaters do not increase boiler efficiency, but merely act as purifiers. Live steam heaters should always be by-passed and so located that the bottom of the shell is at least two feet above the water level in the boiler, thus permitting the purified water to gravitate into the boiler.

23. *Feeding Boilers*.—Water is fed to the boiler by means of an injector or a pump depending upon the size of the plant. The use of an injector does not permit preheating the feed water by means of an open heater; hence relatively cold water is introduced into the boiler, thus decreasing the economy of the plant. It is possible to

install between the injector and the boiler a closed heater, but in such an installation the effectiveness of the heater is decreased because of the heat supplied by the injector. Frequently it is claimed that an injector considered as a combined pump and heater has an efficiency of one hundred per cent since all the heat in the steam used for operating the injector is returned with the water forced into the boiler. Considered as a pump the injector is very inefficient since it requires much more steam to force a given amount of water into the boiler than is required by a pump to do the same amount of work. Furthermore when a pump is used for feeding boilers, the exhaust steam from the pump may be used for preheating the feed water. According to tests, a direct acting steam pump, feeding water through a heater in which the exhaust steam of the feed pump is utilized, shows a much greater saving of fuel than an ejector with or without a heater. In general the feed pump must be located below the water level in the heater, preferably about three feet below, since hot water cannot be lifted by suction.

In order that it may be possible to check the efficiency of the boiler as well as that of the fireman or to determine the most economical fuel, the feed water system should include some form of metering device for measuring the water fed to the boilers. There are a number of metering devices on the market some of which are permanently accurate and some of which must be checked up at frequent intervals. There are now several manufacturers of feed water heaters who are prepared to furnish heaters equipped with water measuring devices.

In addition to measuring the amount of water fed to a boiler, provision should be made for weighing the coal used by each boiler, thus affording a means of determining for each boiler the evaporation per pound of fuel. This will also make it possible to compare the performance of any two boilers in the plant.

For the majority of small boiler plants the feed water should be introduced into the boiler at a constant rate rather than intermittently as is too frequently done.

VII. STEAM PIPING REQUIREMENTS FOR FUEL ECONOMY IN SMALL PLANTS

24. *Possibility of Fuel Loss in the Transmission of Steam.*—In order to promote the economical use of coal, the steam generated should be transmitted to the point of use with as little loss of both heat and steam as practicable. This means that the piping system should be as simple as possible and well insulated. Only short direct runs should be used in connecting boilers, engines, and other apparatus.

All branch lines not in use should have the valves closed so that steam cannot enter them and waste heat by condensing in these dead ends, and the stop valves should be located (Fig. 15) so as to accomplish this purpose. If the engine shown in Fig. 15 is shut down for any length of time the valves at both ends of the engine lead should be closed to prevent steam from condensing in and filling up this lead.

25. *Value of High Pressure Drips as Hot Feed Water.*—Each high pressure header and steam separator should be dripped (Fig. 15) and the hot water returned to the feed-water heater, which should be included in the equipment of every power plant since each 11 degrees F. increase in the feed-water temperature will effect a saving of nearly one per cent in the coal burned. In no case should cold water be fed direct to the boilers, even if live steam has to be used for heating it.

The oily drips from the exhaust steam header (Fig. 15) should be discharged to the sewer or wasted since the oil they carry has an injurious effect upon the boiler tubes and shell, and may do much more harm than the fuel value of the heat contained in these drips is worth.

26. *Leakage Losses at Valves and Fittings.*—The boiler blow-off cock or valve must be perfectly tight to prevent the escape of any hot water to the sewer or other waste channel. If the end of this line cannot be readily inspected to make sure that all blow-off valves are tight, then a tell-tale connection (Fig. 15) with valve should be

placed in the blow-off line beyond the main cock so that by opening it a leak at the blow-off will at once be apparent.

Leaks of hot water or steam which appear in any line either at a valve, flange, or other fitting should be stopped immediately; otherwise a serious waste of fuel may result in making up the heat so lost. An even more serious condition may result if a leak is so located that it discharges water or steam over any part of the boiler or over another pipe since corrosion is very rapid in such a case. In fact, such leaks have started corrosion which later resulted in boiler explosions.

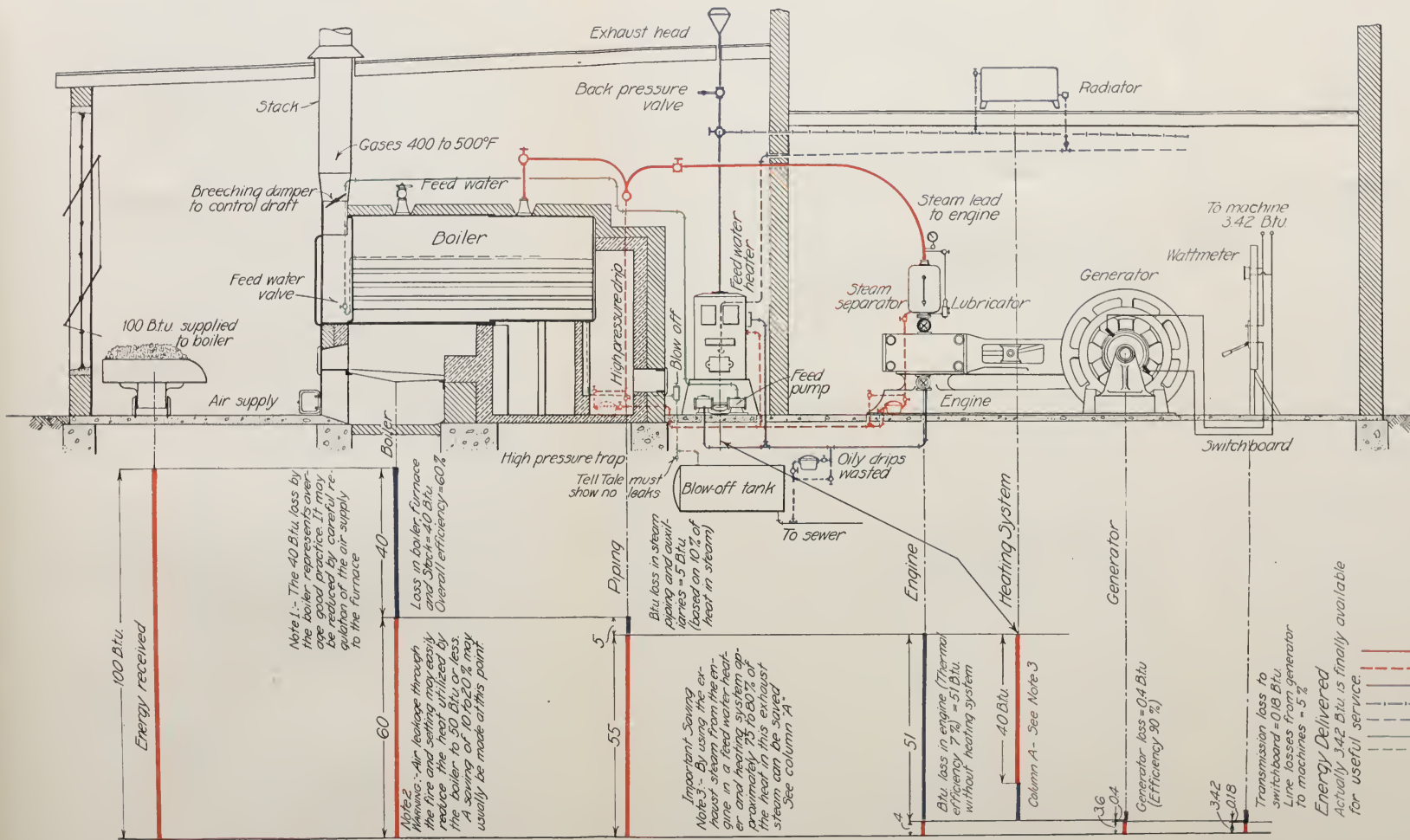
27. *Size of Steam and Exhaust Mains.*—The size and length of steam and exhaust mains may adversely affect the fuel consumption of a plant if these lines are either, (1) too small, or (2) too large for the proper handling of the steam they have to carry. Generally, the lines are too small, but this is not always the case.

If the steam main between boiler and engine is too small or too long, it will be necessary to carry a much higher pressure at the boiler than would otherwise be necessary in order to get the required pressure at the engine. The excessive friction in small steam lines causes this loss in pressure, and if the main is also very long the loss will be still more pronounced. Steam gages at the boiler and at the engine throttle should not show a difference, or a drop in pressure of more than five pounds when the engine is running at full capacity. Should it be necessary to carry a much higher pressure at the boiler than at the engine in order to get a satisfactory operating pressure, some unnecessary coal must be burned since all the heat losses will be slightly increased and leaks will be somewhat more likely to develop.

On the other hand, if this main is too large (which is not so serious) the pressure at the engine throttle will be almost the same as that at the boiler when running at full capacity. The heat losses from oversize pipes and fittings are greater and the first cost of installation is higher than for mains of the proper size.

In the case of the exhaust main, the size is most important since the steam has now expanded and occupies a much greater volume than when it left the boiler. This exhaust steam must be discharged from the engine at the lowest possible back pressure if the engine is to get the most work out of each pound of steam supplied to it and

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- Piping Legend**
- High pressure steam
 - - - " " drips
 - - - Exhaust steam
 - - - " or low pressure steam heating
 - - - Heating return
 - - - Hot feed water
 - - - Blow-off

hence develop the greatest power. With exhaust piping which is too small, a steam gage on the line will show a back pressure of more than two pounds which means that more steam is being taken into the engine to do the work than is necessary. This in turn means coal wasted. Exhaust mains are almost never too large, but in such cases the excess heat loss due to radiation from large exhaust mains is not so serious as in the case of high pressure steam mains since the temperature of exhaust steam is very much less than that of live steam.

28. *Heat Insulating Materials Required on Piping, Boilers, and Breechings.*—The desirability of covering or insulating all high temperature surfaces around a boiler and power plant, when fuel is as expensive and as difficult to obtain as at present, is self evident. It can be shown that by covering all steam and hot-water pipes, fittings, flanges, and valves enough heat can be saved as compared with the loss from bare pipe to pay for the labor and covering material in a very few months. This, of course, applies to the ordinary commercial coverings ranging from one to two inches in thickness. Table 5 shows the saving per year for 100 feet of covered pipe in pounds of coal and in dollars with coal at \$5.00 per ton (2,000 pounds).

The best commercial coverings one inch in thickness will save or prevent the escape of from 75 per cent to 85 per cent of the heat lost from bare pipes. The thickness of the covering should be varied with the temperature of the steam or water in the pipe line, but in general it will pay to use not less than one inch on all lines which are at 200 degrees F. and up to 300 degrees F. Above 300 degrees F. and up to 400 degrees F. it is advisable to use 1½ inch covering and above 400 degrees F., not less than two inches.

The actual heat saving value of commercial pipe coverings now on the market has been the subject of many investigations. The latest work in this field has been done by L. B. McMillan* at the University of Wisconsin and the charts (Figs. 16 and 17) have been made from the results of his tests on bare and covered five-inch steel pipe. These charts show how the heat transmitted by bare pipe compares with the heat transmitted by the same pipe when insulated. The values of only seven of the twenty or more coverings tested are shown. Their efficiency as insulators is easily seen by reading the

* "The Heat Insulating Properties of Commercial Steam Pipe Coverings," Journal, A. S. M. E., Dec., 1915.

TABLE 5

COAL AND STEAM LOSS BASED ON 100 FEET OF UNCOVERED STEEL PIPE

Steam at Gage Pressures of 50, 100, 150, and 200 pounds per square inch. Air Temperature 70 degrees F., feed temperature = 200 degrees F.
 Heating value of coal = 12,000 B. t. u. per pound. Boiler and furnace efficiency = 60 per cent.
 Coal at \$5.00 per ton. Time = 24 hours per day and 365 days per year.

Note.—A good pipe covering will save 75 per cent to 85 per cent of this loss.

Pipe Size	Surface per 100 Lineal Feet	Pressure = 50 Lb.			Pressure = 100 Lb.			Pressure = 150 Lb.			Pressure = 200 Lb.		
		Steam Con- densed per Hour	Coal per Year	Coal Cost per Year	Steam Con- densed per Hour	Coal per Year	Coal Cost per Year	Steam Con- densed per Hour	Coal per Year	Coal Cost per Year	Steam Con- densed per Hour	Coal per Year	Coal Cost per Year
Inches	Square Feet	Pounds	Tons	Dollars	Pounds	Tons	Dollars	Pounds	Tons	Dollars	Pounds	Tons	Dollars
1	34.5	24.3	16.2	81	32.0	20.6	103	38.6	24.1	121	43.8	26.7	134
1¼	43.5	30.6	20.1	101	40.4	25.8	129	48.8	30.7	154	55.3	33.7	169
1½	49.8	35.1	23.2	116	46.2	29.3	147	55.8	35.0	175	63.3	38.5	193
2	62.2	43.8	28.9	145	57.6	36.8	184	69.7	43.4	217	79.1	48.6	243
2½	75.3	53.0	35.0	175	69.8	44.7	224	84.4	52.6	263	95.7	58.7	294
3	91.6	64.5	42.5	213	84.9	54.3	272	102.7	63.9	320	116.4	71.4	357
3½	104.7	73.7	48.6	243	97.0	61.8	309	117.4	73.1	366	133.1	81.5	408
4	117.9	83.0	54.8	274	109.3	69.6	348	132.2	82.3	412	149.9	91.5	458
4½	131.0	92.2	60.4	302	121.4	77.5	388	146.9	91.5	458	166.5	102.1	511
5	145.6	102.5	67.5	338	134.9	86.3	432	163.2	101.6	508	185.1	113.4	567
6	173.6	122.2	80.6	403	160.9	102.9	515	194.6	121.3	607	220.6	134.9	675
7	199.8	140.6	92.4	462	185.2	118.3	592	224.0	139.7	699	253.9	155.5	778
8	226.0	159.1	104.7	524	209.4	133.6	668	253.4	158.1	791	287.2	175.6	878
9	252.3	177.6	116.9	585	233.8	149.4	747	282.9	176.5	883	320.7	196.2	981
10	281.0	197.8	130.1	651	260.4	166.4	832	315.1	196.7	984	357.2	218.6	1093
11	307.8	216.6	142.4	712	285.3	182.2	911	345.1	215.5	1078	391.2	239.2	1198
12	334.0	235.1	154.6	773	309.5	197.5	988	374.5	233.9	1070	424.5	259.7	1299

Curves taken from "The Heat Insulating Properties of Commercial Steam Pipe Coverings" L.B.M. Millan A.S.M.E. Dec. 1915

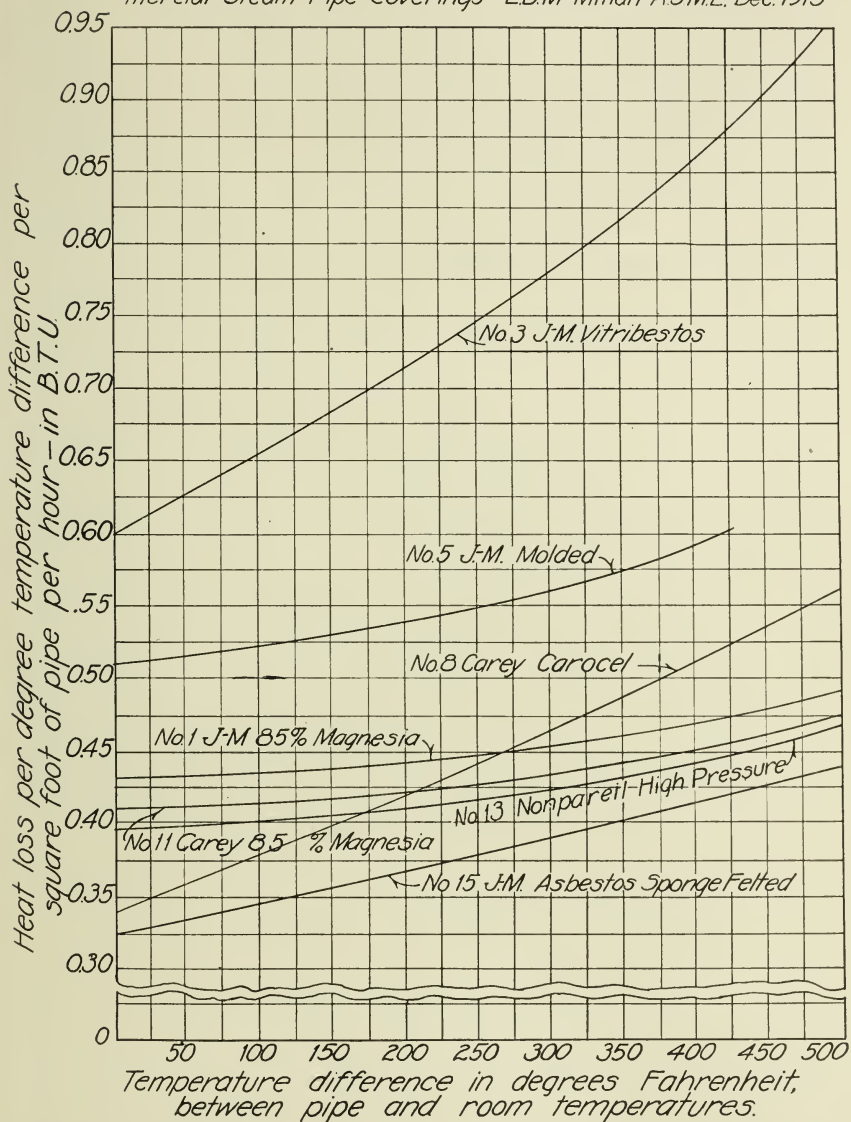


FIG. 16. CHART SHOWING AMOUNT OF HEAT TRANSMITTED BY STEAM PIPES INSULATED WITH COMMERCIAL COVERINGS (See Fig. 17 for Bare Pipe.)

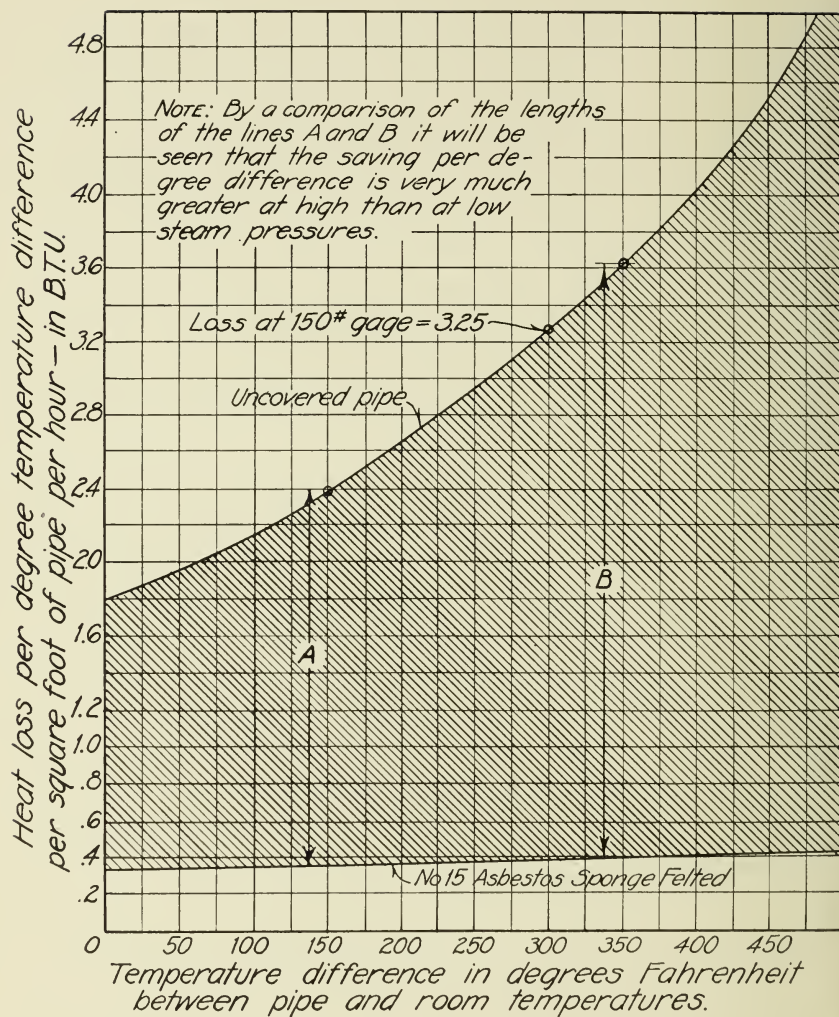


FIG. 17. CHART SHOWING HEAT LOST BY BARE STEAM PIPE AND SAVING WHICH MAY BE SECURED BY USING A GOOD COVERING

scale at the left of the chart, which shows the heat lost or transmitted per hour per square foot of pipe surface per degree difference of temperature between the steam in the pipe and the air outside. The heat loss is expressed in B. t. u.*

* For a definition of B. t. u. see foot-note, p. 17.

The importance of covering steam lines operating at high pressures and temperatures is emphasized by Fig. 17. It will be seen by reference to the upper curve in this diagram that the heat loss per square foot from an *uncovered* five-inch steam line increases very rapidly as the temperature of the steam in the line increases. By covering the line with a good insulator, not only is a large saving effected by reducing the heat loss (see shaded area), but the *increase* in the heat loss per square foot from such a covered line at high temperatures is very much less than for a bare pipe.

In other words, it is most important to cover all high temperature surfaces which are in contact with the air.

The chart (Fig. 17) shows that with steam which is 300 degrees F. above the temperature of the outside air a five-inch diameter standard bare steel pipe transmits about 3.3 B. t. u. per square foot per hour, while the same pipe covered with "Nonpariel High Pressure Covering" transmits (Fig. 16) only 0.425 B. t. u. per hour or thirteen per cent of the heat wasted by the bare pipe. In other words about seven-eighths of the loss has been stopped by the covering.

29. *Requirements for a Good Covering.*—A satisfactory pipe covering must be, (1) unaffected by heat or fire, (2) easily molded and light in weight, (3) impervious to or unaffected by water and steam, (4) non-corrosive in its effect upon metals (steel, iron and brass), (5) structurally fairly strong or self sustaining, and (6) sanitary and not attractive to vermin of any kind. The market affords a great variety of materials at various prices which are used for this purpose. But the purchaser must remember that he is buying heat insulation, not merely covering, and he must assure himself that the material is a practical and effective insulator.

In this connection, it should be noted that the soot which collects on the boiler tubes where no insulation is desired is several times as good an insulator as asbestos, and that the fine ash which also collects on the tubes is almost as good an insulator as soot. In other words, if it is advisable and economical to cover steam pipes with insulation, it is decidedly more economical and necessary to keep boiler tubes absolutely clean and free from the insulating effects of soot and ashes at all times. A similar argument applies to the scale which collects on the water side of the tubes or shell as a result of

infrequent cleaning or failure to employ suitable treatment for the feed water.

30. *Bad Effects of Water of Condensation in Steam Lines.*—Not only does an uncovered steam line waste heat by transmission to the outside air, but it *greatly increases the condensation*, requiring the boilers to furnish more steam than would be necessary in a covered line. It also adds to the amount of water to be handled by the traps, and results in excessive wear on the valve seats and through the steam ports of the engines. If a trap fails to operate properly, the accumulated water may travel along with the steam at high velocity and develop a “water hammer” which will loosen or break some fitting.

31. *Uncovered Pipes Waste Steam as Well as Coal.*—The owner of a power plant should realize that an uncovered steam main wastes heat and that it should therefore be covered. The loss of heat means a loss of steam by condensation and the generation of steam by the boiler plant which cannot be used.

That this loss is serious and that it requires the boilers, the feed pumps, and the traps to handle much more water than would be necessary if the steam mains were properly covered is shown by Fig. 18. The simple computations necessary to prove this statement for a typical case are given below. The plant shown in Fig. 18 is operating 24 hours per day for 365 days per year. A five-inch steam main, which is uncovered, carries steam at 150 pounds gage pressure to an engine 100 feet away. The air around the main averages 70 degrees F. and the feed water enters the boiler at 200 degrees F.

- (1) Actual tests show that each square foot of pipe loses 3.25 B. t. u. per hour for each degree of difference in temperature between steam inside and air outside (Fig. 17).
- (2) The outside surface of 100 feet of five-inch pipe amounts to 145.6 square feet.
- (3) The total heat loss from the pipe per hour is:
$$3.25 \times 145.6 \times (366-70) = 140,000 \text{ B. t. u.}$$

(The temperature of saturated steam at 150-pound gage is 366 degrees F.)
- (4) This heat is obtained *by condensing* not by cooling some of the steam in the pipe. One pound of steam gives up

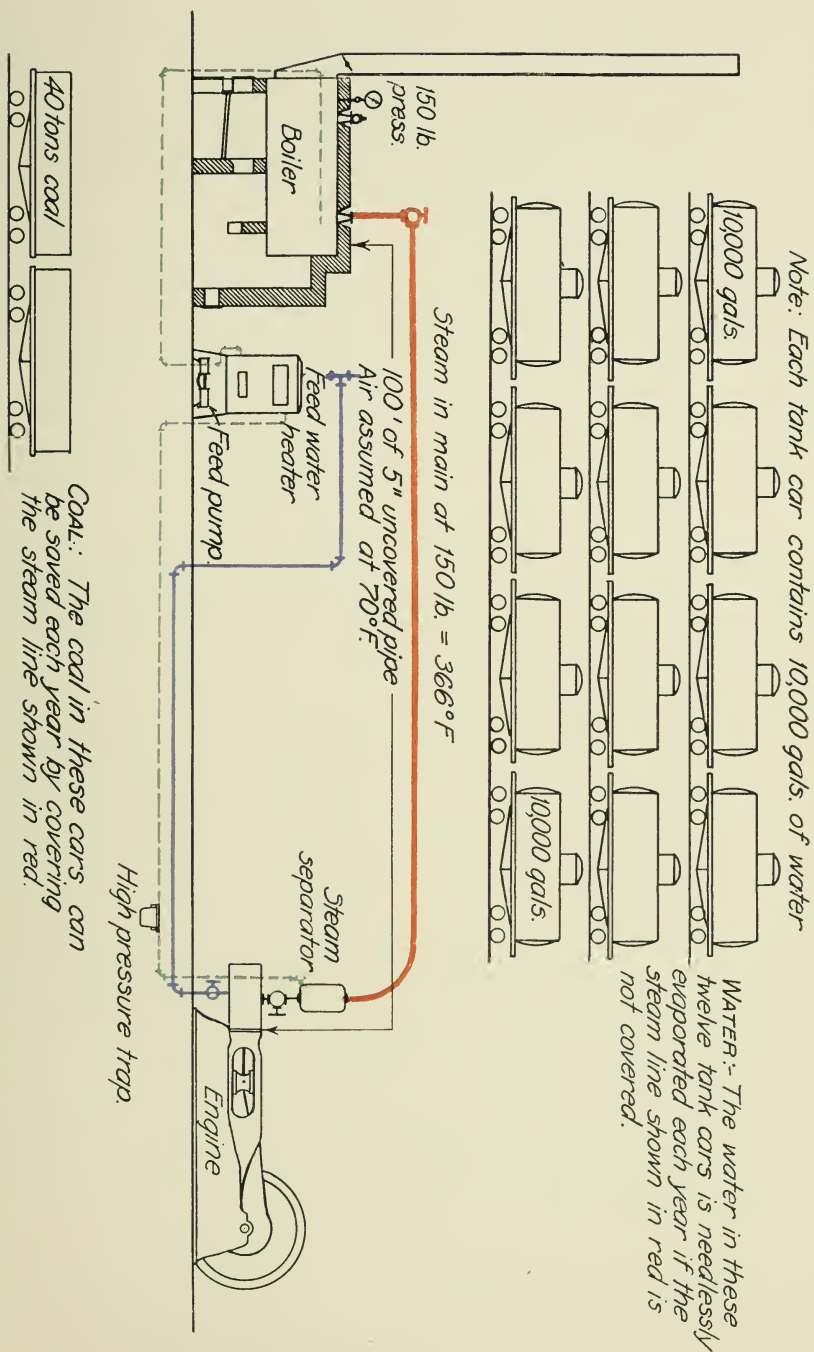


FIG. 18. DIAGRAM SHOWING COMPARATIVE SAVING IN WATER AND STEAM TO BE EFFECTED BY COVERING LIVE STEAM MAINS

858 B. t. u. when it condenses at 150 pounds gage pressure, or the uncovered pipe condenses $\frac{140,000}{858} = 163$ pounds per hour.

- (5) In one year, $163 \times 24 \times 365 = 1,428,000$ pounds of steam wasted; that is, this much steam *never reaches the engine*. At 8 1-3 pounds per gallon, 171,200 gallons of water have been needlessly handled.
- (6) Expressed in another way, this plant has evaporated and sent over 17 tank cars (of 10,000 gallons capacity per car) of water into this line which did not perform useful work. This represents an absolute waste of coal, of steam, and of boiler capacity. At least 75 per cent of this waste could have been prevented by covering the line.
- (7) To evaporate each pound of this water from feed water at 200 degrees F. took $168 + 858 = 1,026$ B. t. u. or a total of $1,026 \times 163 = 167,300$ B. t. u. per hour.
- (8) At 60 per cent efficiency each pound of coal (heat value taken as 12,000 B. t. u. per pound) gives to the boiler 7,200 B. t. u. or the plant is wasting 23.2 pounds of coal per hour to supply the condensation loss.
- (9) The coal required per year is:
 $23.2 \times 24 \times 365 = 203,000$ pounds or 101.5 tons.
- (10) This means that this plant has to burn about $2\frac{1}{2}$ cars of coal (holding 40 tons each), in order to provide for this annual heat loss. A good covering would stop 75 per cent of this waste and save two whole cars or 80 tons of coal a year. Bare steam pipe is a very expensive luxury in any power plant.

The cost of labor and material for covering 100 feet of the five-inch main referred to, including two valves and six fittings, is estimated at about \$160. This is based on present day conditions with the plant located within 150 miles of Chicago, using the best 85 per cent magnesia sectional covering, of $1\frac{1}{2}$ inches in thickness. The use of asbestos sponge felted covering would not add more than four or five per cent to this estimate, and if this work could be executed as part of a large covering job the cost could be reduced about twenty-five or thirty per cent.

VIII. RECORD OF OPERATION

32. *Purpose of the Record.*—The maintenance of such records of operation as may be necessary to enable the superintendent or owner of a plant to determine with reasonable reliability the cost of operation, the relative efficiency of the plant, and the improvement from time to time is essential. For practical purposes, the index to the performance of any steam generating plant lies in the relation between the number of pounds of water evaporated, and the number of pounds of coal fired less the weight of the ash. The record must therefore give the information on the basis of which this relation may be determined at any time, and it should also contain such other data as may be required for detecting and remedying any defects in operation which indicate loss.

33. *Character of the Record.*—It must be recognized that no satisfactory record of operation is possible unless the plant is equipped with certain checking and recording devices which have been recommended in the preceding pages of this discussion. These may be recounted as follows:

- (1) Means of weighing the coal fired for each boiler.
- (2) Means of weighing the ash removed from the pit.
- (3) Some device for weighing or measuring the water fed to the boiler or the steam delivered by the boiler.
- (4) A thermometer for indicating the temperature of the feed water.
- (5) A draft gage connected into the space above the fuel bed and into the ashpit.
- (6) A differential draft gage connected into the space above the fuel bed and into the flue gas passage near the point of discharge from the boiler.
- (7) A CO₂ analyzer.
- (8) A pressure gage at the boiler (pressure gages should also be supplied at the ends of all live steam lines).
- (9) A pyrometer for indicating the temperature of the flue gases leaving the setting.

Some of these devices are already part of the equipment of most

plants and the others may be secured at so slight a cost in proportion to the saving to be effected as easily to warrant their installation.

The weighing of the coal does not present any difficulties. The weighing of the ashes, however, is not so easy owing to the fact that in most plants the ash is wetted down to facilitate handling and to the possibility of a certain amount of unconsumed coal being present in the ash.

The function to be performed by each item of equipment included in the foregoing list has already been explained. The first four items are necessary for arriving at the relationship:

$$\frac{\text{Number of pounds of water evaporated}}{\text{Number of pounds of ash free coal fired}}$$

The last five items of equipment listed are needed to indicate the source of any defects in operation or troubles which may be leading to losses.

The daily record of operation should include the items shown in the form given on page 83.

Items 1, 2, and 3 of this record should cover the entire shift of the firemen for each boiler. Items 4 to 9, inclusive, should contain readings taken for each boiler at regular intervals (the suggested form provides for hourly readings) throughout the shift as frequently as may be practicable. The choice of the individual to be charged with the responsibility of maintaining this record is a matter which will depend largely upon the character and size of the existing organization of each plant. In some cases it may be found satisfactory to entrust the matter to the fireman; in others it may be desirable to assign it to some other employe. It should be recognized in any case that unless the record is maintained with reasonable care and accuracy its value is not great. If carefully kept the record will prove a means of stimulating the interest and coöperation of employes concerned with the operation of the plant as well as the basis for effecting economies the extent of which will in most cases be material.

NAME OF FIRM

DAILY RECORD OF POWER PLANT OPERATION

Date..... 1st shift M to M.

Name of Fireman.....

2nd shift M to M.

Name of Fireman.....

Boiler No. 3rd shift M to M.

Name of Fireman.....

	1st Shift	2nd Shift	3rd Shift
1. No. lb. Coal Fired			
2. No. lb. Ash Removed . . .			
3. No. lb. Water Evaporated .			
4. Temp. of Feed Water . . .			
5. Boiler Pressure			
6. Draft Gage Readings . . .			
7. Differential Gage Readings			
8. CO ₂ Readings			
9. Temperature of Flue Gases			

34. *Profit Sharing or Bonus Systems.*—In some plants the practice is followed of permitting firemen and other employes to share in the savings which result from their efforts. Without undertaking either to commend or to condemn the profit sharing system as applied to power plant operation, the suggestion is offered that in any event no such system should be inaugurated until the plant is put in proper condition, i. e., until the setting has been made tight and is well covered, until live steam pipes are covered, and until such other changes have been made and devices installed as have been herein discussed. Having made these mechanical changes and improvements, the importance of which will be reflected in the results of operation, the earnest coöperation of employes concerned with the plant is essential in securing the maximum benefits, and the application of a profit sharing plan may in some cases prove the means of enlisting this coöperation.

IX. SUMMARY OF CONCLUSIONS

35. *Conclusions.*—To enable the plant owner to determine whether or not his installation conforms with the requirements of practice promoting fuel economy and to check up his methods of operation, the essential features discussed in the preceding pages are summarized as follows:

Coal

- (1) Practically the only fuel available for power plant use in Illinois under present conditions is bituminous coal from the central fields of Illinois, Indiana, and western Kentucky.
- (2) The care with which coal is “prepared,” and separated into different sizes is an important factor affecting its value in the power plant.
- (3) The B. t. u. value and the percentage of ash furnish a general guide to the relative values of Illinois coals. Generally the coals having the lowest ash content have the highest B. t. u. value.
- (4) The storage of bituminous coal is both practicable and desirable. Certain precautions, however, must be observed. These are set forth in detail on page 18.*

Principles to be Observed in Firing

- (5) The three fundamental conditions necessary for complete and smokeless combustion of bituminous coal are:
 - (a) A sufficient amount of air must be supplied.
 - (b) The air and fuel must be intimately mixed.
 - (c) The mixture must be brought to the ignition temperature and maintained at this temperature until combustion is complete.
- (6) Since bituminous coal from the central field is practically the only fuel available at present for power plant use in Illinois the boiler setting and the plant in general should be adapted to the economical use of this fuel.

* See also Univ. of Ill. Eng. Exp. Sta. Circular 6, entitled, “The Storage of Bituminous Coal,” by H. H. Stoeck.

- (7) Every boiler should be equipped with two draft gages, one connected directly in the space over the fire, and one connected both into the space over the fire and into the gas passage below the damper. For every given load, the draft necessary to carry it and the proper thickness of fuel bed with the grade of coal used should be determined.
- (8) In many plants of large and medium size automatic draft control has proved economical, and it is also of advantage in maintaining constant steam pressure.
- (9) Every plant should have some simple type of CO₂ analyzer for obtaining a knowledge of conditions existing within the furnace. (See page 30.)
- (10) Air leakage through the boiler setting should be prevented by properly calking and covering the setting.
- (11) Losses due to the presence of unconsumed coal in the ash should be avoided by seeing that the fire is properly worked and that the grate openings are not too large for the size of fuel fired.
- (12) Sooty deposits on the heating surfaces should be removed frequently. Should the temperature of the gases leaving the boiler exceed 550 degrees F., it probably indicates that the tubes need blowing.
- (13) Scale on the water surfaces of the boiler should not be allowed to accumulate.
- (14) The spreading method of firing in which small quantities of coal are fired at frequent intervals is regarded as a satisfactory method for hand fired plants. (See page 41.)

Features of Boiler Installation

- (15) The foundation for a boiler setting should rest on a firm footing in order to insure a setting which will remain tight and free from any tendency to crack.
- (16) For the complete combustion of bituminous coal boiler settings must provide for the introduction of sufficient air into the furnace, for the proper mixing of this air with the gases given off by the burning coal, and for the maintenance of a high temperature until the process of combustion is complete. This is to be accomplished by means of arches, baffles, and other devices as hereinbefore described. (See page 44.)

- (17) The brick work in setting should be properly pointed up and covered with an insulating material to prevent air leakage. The exposed parts of the shell of horizontal return tubular boilers and of the steam drums of water tube boilers should be covered with a high grade of asbestos insulating material at least two inches thick, or with an 85 per cent magnesia covering two or three inches thick, and the outside finished off with a thin coat of hard cement or covered with canvas and painted. Air spaces in the walls of the setting should be filled with sand or ashes.

Stacks and Breechings

- (18) In order to control the amount of air and flue gas passing to the stack a damper installed at the point where the flue gas leaves the boiler should be regulated so as to permit the stack to supply the right amount of air to burn completely the fuel fired. The air supply should be controlled by this damper and not by opening and closing the ashpit doors, which should stand open practically all the time. Each boiler should have its individual damper.
- (19) The individual boiler dampers should fit accurately and close tight, otherwise it will be impossible to prevent cold air from entering the main breeching through the damper of a "dead" boiler.
- (20) The breeching and stack should be made air tight and should be insulated to prevent heat loss from the flue gases so that all the heat in the gases may be available for creating draft.

Feed Water and Fuel

- (21) If the feed water used causes scale, corrosion, or priming it should be analyzed by a reliable chemist and treated in such manner as he may prescribe.
- (22) It is necessary and economical to heat the feed water. One per cent of fuel is saved for every eleven degrees rise in the feed water temperature.
- (23) For the majority of small boiler plants the feed water should be introduced into the boiler at a constant rate rather than intermittently. The feed water system should include some form of metering device for measuring the water fed to the boiler or the steam delivered by it.

- (24) Means should be provided for weighing the coal fired to each boiler and the ash removed.

Steam Piping Requirements

- (25) The piping system should be as simple as possible and well insulated. Only short direct runs of live steam pipes should be used in connecting boilers, engines, and other steam using apparatus.
- (26) Each high pressure header and steam separator should be provided with drips and the hot water returned to the feed water heater.
- (27) Leakage losses at valves and fittings in all steam and water lines should be stopped at once.
- (28) If a steam main is either too small or too long it will be necessary to carry a higher pressure at the boiler to get the required pressure at the engine. Steam gages at the boiler and at the engine throttle should show a drop in pressure of not more than five pounds when the engine is running at full capacity. If a steam main is too large the pressure at the engine throttle will be almost the same as that at the boiler. The heat losses from oversize pipes and fittings are somewhat greater and the cost of installation is higher than for mains of the proper size. The exhaust piping should be of such size that a gage near the engine will show a pressure of not more than two pounds.
- (29) All steam and hot water piping, fittings, flanges, and valves should be covered with an insulating material. The saving to be affected by such covering is sufficient to repay the cost in the first few months. (See page 76.)

Record of Operation

- (30) A suitable record of operation should be maintained upon the basis of which the superintendent or owner of the plant may determine with reasonable reliability the cost of operation, the relative efficiency of the plant, and the improvement from time to time. From the record of operation it should be possible to determine whether the individual boilers are operating at their rated capacities. In cases in which boilers are operating at less than capacity conditions should be so changed as to require each unit to carry

its full load or an overload. In cases in which it is not possible to balance the load with the combined capacity of units, it is economical to operate as many boilers as possible at capacity and to throw the excess on an extra unit.

- (31) Special emphasis is to be laid upon the problem of the plant owner and upon the part he must play in the program of saving fuel. The economical utilization of fuel in power plants is vital, not so much because it means a cash saving to the owner, but rather because conditions are fast approaching a point at which the owner who does not conserve his fuel may find himself unable to maintain continuous operation.

LIST OF PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

- Bulletin No. 1.* Tests of Reinforced Concrete Beams, by Arthur N. Talbot, 1904. *None available.*
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- Circular No. 2.* Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*
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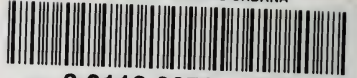
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